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"Read Nature in the Language of Experiment."

MODERN

ELECTRICITY AND MAGNETISM,

THEORETICALLY AND PRACTICALLY CONSIDERED.

BEING

THE CHAPTER ON ELECTRICITY,

FROM

THE ELEMENTS OF NATURAL PHILOSOPHY.

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BY

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PREFACE

THE rapid and remarkable developments in Electrical Science made within the last ten years have been such as to attract the attention of the general public. Ocean and multiplex telegraphy, telephony, electric illumination, electric railways, electric motors, electro-plating dynamos, time telegraph systems and the other countless applications of electricity have come in such rapid succession, been so warmly welcomed and so largely accepted for common use, that the "practical man of business" has been forced to look up from his balance sheet or market report to see what all of these things mean and, perhaps, even to ask, "What next?" Some of them have, it is rumored, been sufficiently interested in the matter to invest **money** in some of the enterprises for adapting this physical mystery to the doing of a part of the world's work. They and their children, their neighbors and their neighbors' children desire and need to know more of the nature and peculiar characteristics of this old but feebly

known acquaintance, who has so suddenly taken so active a part in the affairs of their every-day life. Hence, these pages.

Yesterday, the few studied this subject, largely led by curiosity; to-day, the many, impelled by business or scientific necessity. But the subject has grown and otherwise changed, as well as the class of students. In fact, the latter change is an effect of the former. "Electricity" no longer covers merely a few disjointed phenomena, however interesting and remarkable; it has become a science. A treatise on the subject can no longer be made on the scrap-book plan; it must constantly refer all things to an underlying principle, a stratum on which all is built and by which all is unified.

Electricity is a department of physics and, in its largest sense, physics is the science of *Matter and Energy*.

Introductory Chapter.

As stated in the preface, electricity is a department of physics, which is the science of matter and energy.

Matter is anything that "takes up room" or occupies space. It is always and everywhere subject to the attractive influence of a well-known force called gravitation. The two ideas of extension and weight are inseparably united with the idea of matter.

Atoms, molecules and masses are divisions of matter. Atoms make molecules; molecules make masses. Each of these has its own attraction and its peculiar forms of motion. Electricity and magnetism are, probably, forms of molecular motion, as heat and light, certainly, are.

Scientific men, the world over, generally make use of the international or metric units of weights and measures. The unit of length is the meter (*m.*) and equals 39.37 inches—"a long yard." It is divided successively into tenths, known as decimeters (*dm.*), centimeters (*cm.*) and millimeters (*mm.*). The accompanying figure shows the decimeter (tenth-meter) and its subdivisions. The multiples of all the metric units increase in a ten-fold ratio and are designated by the prefixes, *deka-*, *hekto-*,

FIG. 1.

kilo-, etc. The kilometer (1000 *m.*) equals about 0.62 of a mile. The divisions of all the metric units are designated by the prefixes *deci-*, *centi-*, *milli-*. A cubic centimeter (*cu. cm.*) of pure water at its temperature of greatest density furnishes the unit of weight and is called a gram (*g.*). A kilogram (*Kg.*) equals 2.2 lb. avoirdupois. A cubic decimeter furnishes the unit of capacity. It is called a liter (pronounced *leeter*) and, in value, is between the liquid and the dry quart. A liter of pure water weighs a kilogram. A milliliter (*ml.*) of water, of course, weighs a gram.

Force is a term used to designate any cause that tends to produce, change or destroy motion. Equal forces produce equal velocities when applied to equal bodies for equal times. The unit of force generally used in scientific work is the dyne. This is the force that, acting for one second on a mass of one gram, produces a velocity of one centimeter per second. It is one of the "absolute" or "C. G. S." (centimeter-gram-second) units. The weight of a gram equals about 980 dynes.

Work is the overcoming of resistance. Work implies a change of position and is independent of the time taken to do it. The foot-pound is the unit of work most commonly used in this country, as yet. It is the work done in lifting a mass of one pound (avoirdupois) one foot high against the force of gravity. The work done in lifting a mass of one kilogram one meter high against the force of gravity is called a kilogram-meter. The C. G. S. unit of work is called an erg. It is the work done in moving a free body one centimeter against a force

of one dyne. The work of lifting one gram one centimeter high against the force of gravity is about 980 ergs. A foot-pound is about 13,560,000 ergs.

The rate of doing work is called power. A horse-power represents the ability to perform 550 foot-pounds in a second or 33,000 foot-pounds in a minute. It equals about 746×10^7 ergs per second.

Energy is the power of doing work. A mass of matter in motion is able to overcome resistance, or to do work, by virtue of its weight and velocity. Energy of motion, like that of a falling hammer, or of flowing water, is called kinetic energy. But matter often has a supply of *possible* energy by virtue of a position of advantage. Thus a bent bow, the raised weights of a clock or the water in a high reservoir, has a power of doing work by reason of its position alone. Such energy is called potential energy. It is evident that potential energy is easily converted into kinetic energy and *vice versa*. Both of these kinds of energy may pertain to masses of matter, as in the illustrations just given, or to the molecules of matter. The energy of vibrating molecules (molecular, kinetic energy) does the work of the steam engine and, in the case of the expansion of metals by heat, is practically irresistible. We shall have much to do with molecular energy in the following pages.

The various ideas, thus briefly discussed in this introductory chapter, are more fully considered in the opening chapters of *Avery's Elements of Natural Philosophy*, to which the reader is respectfully referred. The rest of this book constitutes a chapter of the revised and enlarged edition of that work. The subject of Electrical Measurements is considered in the Appendix.

CHAPTER VI.

ELECTRICITY AND MAGNETISM.

SECTION I.

GENERAL VIEW.

Note.—A desire to secure favorable atmospheric conditions for experiments in frictional electricity has determined the order in which the following branches of physics are taken up. In most places in this country, the school-year begins with September. In such cases, this chapter would probably be reached by January, during which month the atmosphere is generally dry. Under other circumstances, the consideration of these subjects would better be omitted until sound, heat and light have been studied. The experiments in this chapter are numbered consecutively.

302. Simple Apparatus. — Provide two stout sticks of sealing-wax and one or two pieces of flannel folded into pads about 20 centimeters (8 inches) square; two glass rods or stout tubes closed at one end, 30 or 40 centimeters in length and about 2 centimeters in diameter (long "ignition tubes" will answer) and one or two silk pads about 20 centimeters square, the pads being three or four layers thick; a few pith balls about 1 centimeter in diameter (whittle them nearly round and finish by rolling them between the palms of the hands); a silk ribbon about an inch wide and a foot long; a balanced straw

about a foot long, represented in Fig. 119. The ends of the straw carry two small discs of paper (bright colors preferable) fastened on by sealing-wax. The cap at the middle of the straw is a short piece of straw fastened by sealing-wax. This is supported upon the point of a sewing-needle, the other end of which is stuck upright into the cork of a small glass vial. From the ceiling or other convenient support, suspend one of the pith balls by a fine silk thread.

FIG. 119.

(*a.*) The efficiency of the silk pad above mentioned may be increased by smearing one side with lard and applying an amalgam made of one weight of tin, two of zinc and six of mercury. The amalgam that may be scraped from bits of a broken looking-glass answers the purpose admirably.

Experiment 1.—Draw the silk ribbon between two layers of the warm flannel pad with considerable friction. Hold it near the wall of the room. *The ribbon will be drawn to the wall and held there for some time.* Place a sheet of paper on a warm board and briskly rub it with india-rubber. Hold it near the wall as you did the ribbon.

Experiment 2.—Briskly rub the sealing-wax with the flannel and bring the wax near the suspended pith ball. The ball will be drawn to the wax. Bring the wax near one end of the balanced straw; it may be made to follow the wax round and round. Bring it near small scraps of paper, shreds of cotton and silk, feathers and gold leaf, bran and sawdust and other light bodies; *they are attracted to the wax.*

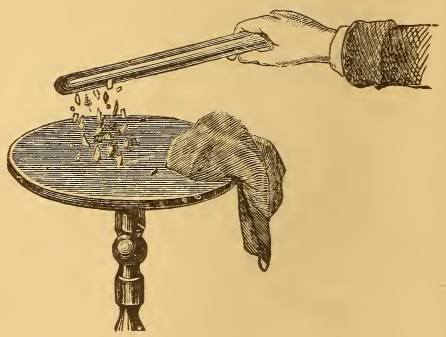


FIG. 120.

Experiment 3.—Repeat all of these experiments with a glass rod that has been rubbed with the silk pad.

Experiment 4.—Make a light paper hoop or an empty egg-shell roll after your rod. (See § 332 *b*.)

Experiment 5.—Place an egg in a wine-glass or an egg-cup. Upon the egg, balance a yard-stick or a common lath. The end of the stick may be made to follow the rubbed rod round and round. Place the blackboard pointer or other stick in a wire loop (Fig. 121) or stiff paper stirrup suspended by a stout silk thread or narrow silk ribbon. It may be made to imitate the actions of the balanced straw or lath.

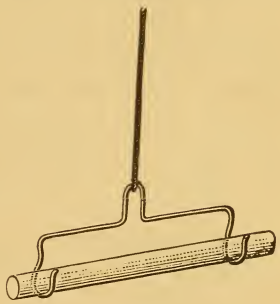


FIG. 121.

Experiment 6.—Suspend the rubbed sealing-wax or glass rod as you did the blackboard pointer in the last experiment. Hold your hand near the end of the rod. *It will turn round and approach your hand.*

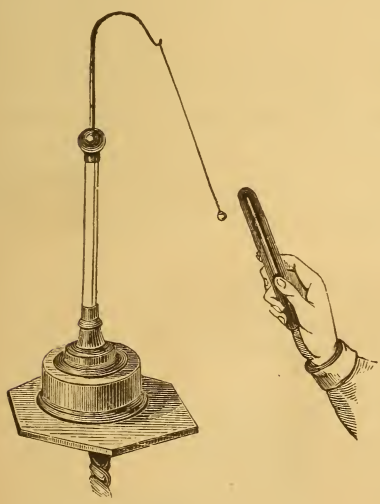


FIG. 122.

Note.—The pupil may be ingenious enough to *invent new experiments* for himself and the class. The ability to invent is often very valuable and may be acquired early in life. Most of the great inventors began making experiments when mere children.

303. Electric Attraction. — *The attractions manifested in the experiments just described were due to electricity that was developed by friction. Such electricity is called frictional or static electricity.*

Experiment 7.—Bring the rubbed sealing-wax or glass rod near the pith ball again. It will attract the ball as before. Allow the ball to touch the rod and notice that, in a moment, the ball is thrown off. If the ball be pursued with the rod, it will be found that *the rod which attracted it a moment ago now repels it.* Evidently, the ball has acquired a new property. (Fig. 123.)

Experiment 8.—Touch the ball with the finger. It seeks the rubbed rod, touches the rod, flies from the rod. Repeat the experiments with the sealing-wax after it has been rubbed with flannel.

Experiment 9.—Rub the glass rod with silk and bring it over the small scraps of paper as before. Notice that, after the attraction, the paper bits do not merely fall down, *they are thrown down.*

304. Electric Repulsion. — *The repulsions manifested in the experiments just described were due to static electricity.* The glass or wax is said to be electrified by friction. The ball, after obtaining its new property of repulsion by coming in contact with the glass or wax, is said to be electrified by conduction. The suspended pith ball is called an *electric pendulum.*

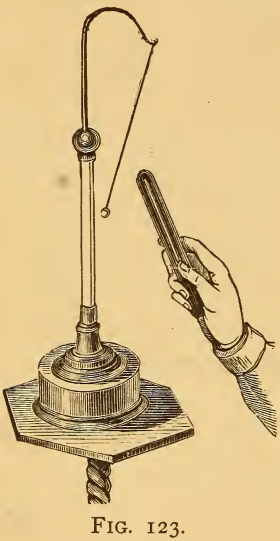


FIG. 123.

Experiment 10.—Prepare a battery solution according to the recipe given in § 392, using only half the quantity of each substance as therein directed. While the solution is cooling, provide a piece of sheet copper and one of sheet zinc, each about 10 centimeters (4 inches) long and 4 centimeters (1½ inches) wide. To one end of each strip, solder (see Appendix B) or otherwise fasten a piece of No. 18 copper wire (See Appendix I) about 15 centimeters (6 inches) long. Place the zinc strip in a common tumbler about three-fourths full of the battery solution. Notice the minute bubbles that break away from the surface of the zinc and rise to the surface of the

liquid. These are bubbles of hydrogen, a combustible gas. *The formation of the gas is due to chemical action between the zinc and the liquid.*

Experiment 11.—Take the zinc from the tumbler and, while it is yet wet, rub a few drops of mercury (quicksilver) over its surface until it has a brilliant, silver-like appearance. Replace the zinc, thus amalgamated, in the solution and notice that *no bubbles are given off.*

Experiment 12.—Place the copper strip in the liquid, taking care that it or its wire does not touch the zinc or its wire. *No bubbles appear either on the zinc or the copper.* It may be convenient to place a narrow glass strip between the ends of the metal strips in the tumbler to keep them apart.

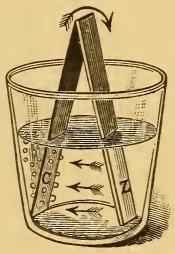


FIG. 124.

Experiment 13.—Bring the upper ends of the strips together, as shown in Fig. 124, or, still better, join the two wires, as shown in Fig. 179, being sure that the wires are clean and bright where they are united. *Notice the formation of bubbles on the surface of the copper, where none previously appeared.*

305. Suspicion.—It seems that the connecting wire is an important part of the apparatus as now arranged and we are led to suspect that something unusual is taking place in the wire itself. It is evident that we have a complete "circuit" through the liquid, the metal strip and the wire.

Experiment 14.—Untwist the wires or, in other words, "break the circuit." Connect the copper wires with a short piece of *very fine* iron wire. The connections should be made so that the circuit shall include about 2 centimeters ($\frac{3}{4}$ inch) of iron wire. *The iron will become hot* enough to burn the fingers or to ignite a small quantity of gun cotton twisted around it.

FIG. 125.

Experiment 15.—If one of the copper wires be twisted around one end of a small file and the free end

of the other wire be drawn along its rough surface, *a series of minute sparks will be produced* as the circuit is rapidly made and broken.

Experiment 16.—Place the cell so that the joined wires shall run north and south, passing directly over the needle of a small compass (Experiment 98) and near to it. *The needle will instantly turn* as though it were trying to place itself at right angles to the wire. Break the circuit and the needle will swing back to its north and south position.

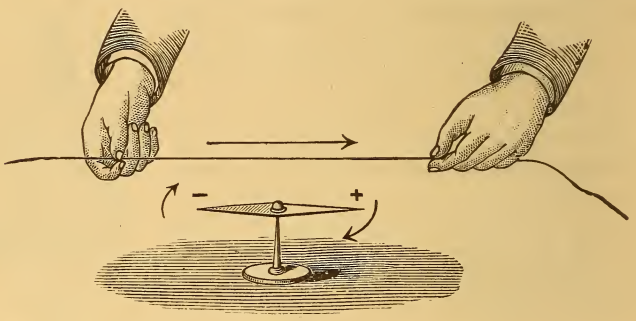


FIG. 126.

306. Certainty.—We now feel sure that something unusual is taking place in the wire of our complete circuit, for we have seen the wire become hot, explode gun-cotton, yield sparks and exert a very mysterious influence upon the magnetic needle. As a matter of fact, we now have a current of electricity flowing through a voltaic cell and wire. *Electricity thus produced by chemical action is called voltaic or galvanic electricity. It is one form of current electricity.*

Experiment 17.—Wrap a piece of writing paper around a large iron nail, leaving the ends of the nail bare. Wind fifteen or twenty turns of stout copper wire around this paper wrapper, taking care that the coils of the wire spiral do not touch each other or the iron. It is well to use cotton covered or "insulated" wire. Connect the two ends of the wire spiral with the two wires of the voltaic cell

or, in other words, put the spiral into the circuit. Dip the end of the nail into iron filings. *Some of the filings will cling to the nail in a remarkable manner.* Upon breaking the circuit, the nail instantly loses its newly acquired power and drops the iron filings.

If the experiment does not work satisfactorily, look carefully to all the connections of the circuit, see that the ends of the wires are clean and bright and that they are twisted together firmly. It may be necessary to wash the plates, rub more mercury on the zinc and provide a fresh battery solution.

307. Temporary Magnets.—The nail has the power of attracting iron filings *while the electric current is flowing through the surrounding wire coil. You have made an electro-magnet. Its power of attracting iron is called magnetism.* Satisfy yourself, by trial, that the nail loses its magnetism as soon as the circuit is broken or the current ceases to flow around it. Remember that your electro-magnet is a *temporary magnet.*

Experiment 18.—While the nail is magnetized, draw a sewing-needle four or five times from eye to point across one end of the electro-magnet. Dip the needle into iron filings; *some of them will cling to each end of it.*

308. Permanent Magnets. — When steel is treated as in the last experiment, it becomes permanently magnetized.

Experiment 19.—Cut a thin slice from the end of a vial cork and, with its aid, float your magnetized needle upon the surface of a bowl or saucer of water. *The needle comes to rest in a north and south position.* Turn it from its chosen position and notice that, after each displacement, it resumes the same position and that *the same end of the needle always points to the north.*

309. A Simple Compass.—*A small magnetized steel bar freely suspended, is called a com-*

pass. The one that you have made may be less convenient than is the compass of the mariner or the surveyor, but it is as reliable.

310. Artificial Magnets.—The electro-magnet and the permanent magnet that you make are, of course, *artificial magnets.* There is a *natural magnet* known as lodestone.

311. Other Forms of Current Electricity.—Electric currents may be generated by the action of other currents of electricity or by the action of magnets. Electricity thus developed is called *induced electricity.* A current of *thermo-electricity* may be generated by heating the junction of two metals that form part or all of a circuit.

312. The Different Forms of Electricity are Identical.—So far as experiment can show, one form of electricity may have a particular property in greater degree than some other form, but all are identical, each having all the properties of any of the others.

Recapitulation.—To be amplified by the pupil for review.

SECTION II.

FRICTIONAL ELECTRICITY OR ELECTRIC CHARGES.

313. The Nature of Electricity.—But little is known concerning the real nature of electricity. It is easier to tell what electricity can do than to tell what it is. The majority of modern physicists consider that *electricity is a form of energy producing peculiar phenomena; that it may be converted into other forms of energy and that all other forms of energy may be converted into it.* It is believed that electricity is a form of molecular motion, but this belief still rests upon analogy rather than demonstration. Several theories have been advanced to account for electrical phenomena, but none of them is satisfactory.

314. Electric Manifestations. — *Electricity may reveal itself as a charge residing on the surface of a body or as a current flowing through its substance.* By means of friction, the glass rod or the sealing-wax (§§ 303, 304) acquired an electrical charge and, consequently, the power of attracting and repelling light bodies; by means of chemical action, the voltaic cell (§ 306) generated electricity that manifested itself as a current. *In this section, we shall consider electricity that appears as a charge, i.e., static electricity.*

(*a.*) The electrified body is said to be charged. When the electricity is removed, the body is said to be discharged. Good conductors (§ 324) are instantly discharged when touched by the hand, or by any good conductor connected with the earth. A poor conductor may be readily discharged by passing it rapidly through a flame, as of a lamp or candle.

Experiment 20.—Prepare two electric pendulums. Bring the electrified glass rod near the pith ball of one; after contact, the ball will be repelled by the glass. Bring the electrified sealing-wax near the second pith ball; after contact, it will be repelled by the wax. Satisfy yourself that the electrified glass will repel the first; that the electrified sealing-wax will repel the second. Let the glass rod and the sealing-wax change hands. The first ball was repelled by the glass; *it will be attracted by the sealing-wax.* The second ball was repelled by the sealing-wax; *it will be attracted by the glass.*

Experiment 21.—Suspend two pith balls as shown in Fig. 127, and touch them with a rubbed glass rod. Instead of continuing to hang side by side, they repel each other and fly apart. If the electrified glass rod be held near them, they separate still further. If the electrified sealing-wax, instead of the glass, be held near them, they will fall nearer together. If the rubbed glass rod be suspended as shown in Fig. 121, it will be repelled by another rubbed glass rod, but attracted by rubbed sealing-wax.

FIG. 127.

315. Two Kinds of Electricity.—*The electricity developed on glass is different in kind from that developed on sealing-wax.* They exhibited opposite forces to a third electrified body, each attracting what the other repels.

Experiment 22.—Hold the silk pad in a piece of sheet-rubber and, with it, rub the glass rod. Suspend the glass rod and bring the silk pad near it. The electrified pad will attract the glass, but will repel a suspended stick of sealing-wax that has been rubbed with flannel.

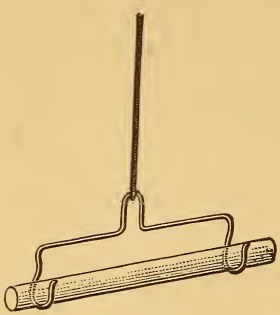


FIG. 128.

316. Electric Separation.—*All electrified bodies act like either the glass or the sealing-wax.* When the glass rod was positively electrified, an equal amount of negative electricity was simultaneously developed in the silk with which it was rubbed. When the sealing-wax was negatively electrified, an equal amount of positive electricity was developed at the same time in the flannel. It is as though the two electricities were united in these several substances in their ordinary condition and were torn asunder by the friction, thus producing actual "electric separation."

(*a.*) If it be desired to show that the rubber has been electrified, care must be taken not to handle it too much. For example, if sealing-wax is to be rubbed with a piece of fur, do not take the fur in the hand, but fasten it to the end of a glass rod as a handle.

(*b.*) That the electricities thus simultaneously developed are opposite in kind and equal in amount may be shown by imparting the electricity of the rubber and the electricity of the thing rubbed to a third body, which will then show no electrification at all. The equal and opposite electricities exactly neutralize each other.

317. The Two Electricities Named.—As the two kinds of electricity are opposite in character, they have received names that indicate opposition. *The electricity developed on glass by rubbing it with silk*

is called positive or +. The electricity developed on sealing-wax by rubbing it with flannel is called negative or —. The terms *vitreous* and *resinous* respectively were formerly used.

318. Electric Series.—In the following list, the substances are named in such an order that, if any two be rubbed together, the one that stands earlier in the series becomes positively electrified and the one that is mentioned later becomes negatively electrified: *fur, wool, resin, glass, silk, metals, sulphur, india-rubber, gutta percha, collodion.*

319. The Laws of Electrostatics.—The most important electrostatic laws may be stated thus:

(1.) *Electric charges of like signs repel each other; electric charges of opposite signs attract each other.*

(2.) *The force exerted between two electric charges is directly proportional to their product and inversely proportional to the square of the distance between them.* This is known as Coulomb's law. The two charges are supposed to be collected at two points, or on two very small spheres. $f = \frac{Q \times q}{d^2}$.

(*a.*) Suppose that *a* and *b* are two small balls, each charged with a quantity of electricity, that we shall call unity. Then the product of the charges will be $1 \times 1 = 1$. Next, suppose that *A* and *B* are two similar balls, that *A* is charged with twice as much electricity as *a* and that, similarly, *B* has a charge represented by 3. The product of the charges of *A* and *B* will be $2 \times 3 = 6$. In other words, at equal distances, the repulsion between *A* and *B* will be six times as great as the repulsion between *a* and *b*.

(*b.*) Suppose that two electric charges or two small electrified bodies one inch apart repel each other with a certain force; at a distance of two inches, they will repel each other with a force one quarter as great; at a distance of ten inches, they will repel each other with only one *per cent.* of the original force at the distance of one inch.

320. Electrical Units.—There are two systems of electrical units derived from the fundamental "C.G.S." units, one set being based upon the attraction or repulsion exerted between two quantities of electricity and the other upon the force exerted between two magnet poles. The former are termed *electrostatic* units; the latter, *electromagnetic* units.

321. Electrostatic Unit of Quantity.—*One unit of electricity is that quantity which, when placed at a distance of one centimeter from a similar and equal quantity, repels it with a force of one dyne.* It is a C.G.S. unit (§ 69) and has no special name.

(*a.*) Two small spheres, charged respectively with 6 units and 8 units of + electricity, are placed 4 *cm.* apart; find what force they exert on one another.

By the formula, $f = \frac{Q \times q}{d^2}$, we find $f = \frac{6 \times 8}{4^2} = \frac{48}{16} = 3$.

Ans. 3 dynes.

The force in the above example would clearly be a force of repulsion. Had one of these charges been negative, the product, $Q \times q$, would have had a − value (algebraic) and the answer would have been *minus* 3 dynes. The algebraic − sign, therefore, prefixed to a force, indicates that it is a force of *attraction*, while the + sign signifies a force of *repulsion*.

322. The Test for Either Kind of Electricity.—When the pith ball was attracted by the rubbed glass it became, during the time of contact, charged with the + electricity of the glass; hence it was repelled. When it was attracted by the rubbed sealing-wax it became, during the time of contact, charged with the − electricity of the wax; then it was repelled. But either

the wax or the glass attracted the uncharged pith ball. We must, therefore, remember that *attraction affords no safe test for the kind of electricity, while repulsion does.* If glass rubbed with silk repels a body, that body is charged with + electricity. If sealing-wax rubbed with flannel repels a body, that body is charged with — electricity.

323. Electroscopes.—*An instrument used to detect the presence of electricity, or to determine its kind, is called an electroscope.* The electric pendulum (§ 304) is a common form of the electroscope. Two strips of the thinnest tissue paper hanging side by side constitute a simple electroscope. It is well to prepare the paper beforehand by soaking in a strong solution of salt in water and drying. The balanced straw (Fig. 119) or, better yet, two gilded pith balls connected by a light needle of glass or sealing-wax balanced horizontally on a vertical pivot, or a goose-quill balanced on the point of a sewing-needle, makes a convenient electroscope.

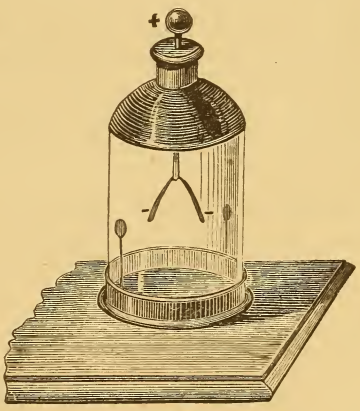


FIG. 129.

The gold leaf electroscope is represented in Fig. 129. A metallic rod, which passes through the cork of a glass vessel, terminates below in two narrow strips of gold leaf and above in a metallic knob or plate. The object of the vessel is to protect the leaves from disturbance by air currents. The upper part of the glass is often

coated with a solution of sealing-wax or shellac in alcohol, to lessen the deposition of moisture from the atmosphere. This instrument may be made by the pupil and, when well made, is very delicate.

(*a.*) The electric pendulum is used as an electroscope as follows: If an uncharged pith ball be attracted by a body brought near it, the body is electrified. To determine the sign of the electricity of the body thus shown to be electrified, the pith ball is allowed to touch it and be repelled. If the ball then be repelled by a glass rod rubbed with silk (or by any other body known to be positively charged), the pith ball and the body in question manifest + electricity. If the pith ball, after repulsion by the body whose electricity is under examination, be repelled by sealing-wax rubbed with flannel (or by any other body known to be negatively charged), the pith ball and the body in question manifest — electricity. Remember that the repulsion and not the attraction constitutes the test.

(*b.*) One way of testing with the gold leaf electroscope is to bring the electrified body *near* the knob; the leaves will diverge. Touch the knob with the finger; the leaves will fall together. Remove first the finger and then the electrified body; the leaves will diverge again. If now the divergence of the leaves be increased by bringing a positively charged body near the knob, the original charge was — ; if the divergence be thus diminished, the original charge was +.

(*c.*) The knob and rod of the gold leaf electroscope may be made by soldering a wire to a smooth metal button. The vessel may be any clear glass bottle with a wide mouth. Thrust the wire downward through the cork of the bottle and bend the wire at right angles, so that when the cork is in place the horizontal part of the wire shall be about $\frac{3}{4}$ inch long and come just below the shoulder of the bottle. Cut a strip of gold or Dutch leaf, 4 inches long and $\frac{1}{2}$ inch wide and paste it at its middle line to the horizontal part of the wire, so that the two halves of the strip shall hang downward facing each other. See that the cork is perfectly dry; heat the bottle until it is perfectly dry; insert the cork firmly in its place, and pour melted sealing-wax over the cork and around the mouth of the bottle so that no moisture can get into *your electroscope.* If you cannot get the gold or Dutch leaf (try at some good-natured dentist's or sign painter's), use two discs of gilt paper as large as the mouth of your bottle will admit and tie them to the wire by very short cotton or linen threads.

Experiment 23.—From a horizontal glass rod or tightly-stretched silk cord, suspend a fine copper wire, a linen thread and two silk threads, each at least a meter long. To the lower end of each, attach a metal weight of any kind. Place the weight supported by the wire upon the plate of the gold leaf electroscope. Bring the electrified glass rod near the upper end of the wire; the gold leaves *instantly* diverge. Repeat the experiment with the linen thread; *in a little while* the leaves diverge. Repeat the experiment with the dry silk thread; the leaves do not diverge *at all.* Rub the rod upon the upper end of the silk thread; no divergence *yet appears.* Wet the second silk cord thoroughly and, with it, repeat the experiment; the leaves then diverge *instantly.*

Experiment 24.—Support a yard stick or common lath upon a glass tumbler. Bring the glass rod, electrified by rubbing it with silk, to one end of the stick and hold some small pieces of gold leaf or paper under the other end of the stick. The gold leaf or paper will be attracted and repelled by the stick as it previously was by the glass itself. *The electricity passed along the stick from end to end.*

324. Conductors.—Such experiments clearly show that *some substances transmit electricity readily and that others do not. Those that offer little resistance to the passage of electricity are called conductors; those that offer great resistance are called non-conductors or insulators.* A conductor supported by a non-conductor is said to be insulated.

(*a.*) In the following table, the substances named are arranged in the order of their conductivity:

Conductors.	5. Salt water.	10. Cotton.	15. Porcelain.
1. Metals.	6. Fresh water.	11. Dry wood.	16. Glass.
2. Charcoal.	7. Vegetables.	12. Paper.	17. Sealing-wax.
3. Graphite.	8. Animals.	13. Silk.	18. Vulcanite.
4. Acids.	9. Linen.	14. India rubber.	*Insulators.*

(*b.*) The fact that a conductor in the air may be insulated, shows that air is a non-conductor. Dry air is a very good insulator (at least 10^{26} times as good as copper), but moist air is a fairly good conductor for electricity of high potential. *All experiments in frictional electricity should, therefore, be performed in clear, cold weather*

when the atmosphere is dry, for a moist atmosphere renders insulation for a considerable length of time impossible.

(*c.*) A simple way of determining experimentally whether a body is a good conductor or not is, to hold it in the hand and touch the knob of a charged gold leaf electroscope with it. If the substance be a good conductor, the electroscope will be quickly discharged.

Experiment 25.—Suspend a copper globe or other metal body by a silk thread and strike it two or three times with a cat's skin or fox's brush. Bring the gold leaf electroscope near the globe. The leaves will diverge.

325. Electrics.—*Any substance, when insulated, may be sensibly electrified; but when an uninsulated conductor is rubbed, the electricity escapes as fast as it is developed.* The old division of bodies into electrics and non-electrics, or bodies that can be electrified and those that cannot be electrified, is nothing more than a division into conductors and non-conductors.

326. Tension.—Electricity exists under widely different conditions with respect to its ability to force its way through a poor conductor or to leap across a gap. The electricity developed in a voltaic cell will not pass through even a very thin piece of dry wood; the electricity developed by rubbing the glass rod will pass through several feet of dry wood. It would require a battery of many cells to force a current across an air-filled gap of $\frac{1}{1000}$ of an inch. It is not difficult to force frictional electricity across a gap of several inches, while we all know that, in the case of lightning, electricity leaps across a gap of many hundred feet. In the one case, the electricity is said to be of low potential; in the other case, it is said to be of high potential. The terms "low tension" and "high tension" are often used in the same sense.

327. Potential.—The term, electrical potential (or simply potential), has reference to the electrical condition of a body, or to its degree of electrification. If the potential of A be higher than that of B and the two bodies be connected by a good conductor, *an electric current will flow from A to B until the potentials are alike.* Difference of potential is somewhat analogous to difference of liquid level and gives rise to electromotive force.

(*a.*) The electric condition of the earth is sometimes taken as the zero of potential. The electric condition of other bodies is then described as being a certain number of units above or below zero; *i.e.*, as being + or −. In determining the flow of liquids, it is not necessary to know the height of either reservoir above the earth's centre or above the sea level, but only the head *or difference of liquid level.* Similarly, *the difference of potential* is what determines the direction and strength of an electric current flowing through a given conductor.

328. Difference of Potential.—*The difference of potential between two points represents the work that must be done in carrying a + unit of electricity* (§ 321) *from one point to the other.* The work done will be the same, whatever the path along which the unit is moved from one point to the other. Similarly, the work done in lifting a weight from one point to another at a higher level will be the same whatever the path along which the weight is lifted.

329. Electrostatic Unit of Difference of Potential.—*The unit of difference of potential is that which exists between two points, when it requires the expenditure of one erg to bring a unit of + electricity from one point to another against*

the electric force. Let A be a small sphere positively electrified and P and Q, two points at different distances from A. If Q is just so far from P that it requires one erg of work to push a unit of + electricity from Q to P, there will be unit difference of potential between P and Q. This unit has no special name.

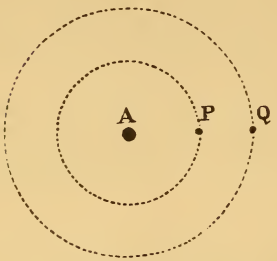


FIG. 130.

(*a.*) Let P and Q be in the outer surfaces of concentric, spherical, shells at the centre of which is A. To move the + unit from one point in either of these surfaces to any other point in the same surface requires no further overcoming of electric forces and, therefore, no expenditure of work. Such a surface is called an *equipotential surface.*

330. Electric Capacity.—Bodies vary in respect to their capacity for holding or accumulating electricity. *The electrostatic unit of capacity is the capacity of a conductor that requires a charge of one unit of electricity to raise its potential from zero to unity.* It has no special name. A sphere of one centimeter radius has unit capacity. The capacities of spheres are proportional to their radii. (See § 359.)

(*a.*) A small conductor (*e.g.*, a sphere the size of a pea) will require less than one unit to raise its potential from 0 to 1; it is of small capacity. A sphere five meters in diameter will require many units to raise its potential from 0 to 1; it is of great capacity. In other words, the electrostatic capacity of a conductor or condenser is measured by the quantity of electricity which must be imparted to it in order to raise its potential from 0 to 1.

331. Charging by Contact.—If an insulated, unelectrified conductor be brought into contact with a simi-

lar conductor that is electrified, or near enough to it for the easy passage of an electric spark, electricity will pass from the latter to the former until the two conductors are equally charged with the same kind of electricity, *i.e.*, until they are of the same potential. *The former is said to be charged by conduction.*

332. Electrostatic Induction.—From several of the preceding experiments, we see that actual contact with an electrified body is not necessary for the manifestation of electric action in an unelectrified body. When an electrified body, *C*, is brought near an insulated, unelectrified conductor, *B*, provided with electric pendulums, as shown in Fig. 131, the latter shows electric action. The electricity of *C* repels one kind of electricity in *B* and attracts the other, thus separating them. The second body, *B*, is then said to be *polarized*.

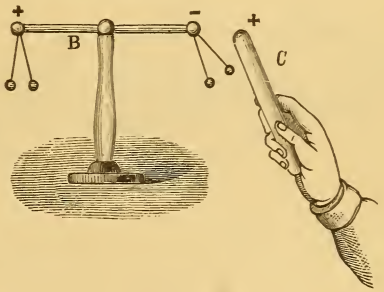


FIG. 131.

The two kinds of electricity in *B*, each of which a moment ago rendered the other powerless, are still there, but they have been separated and each clothed with its proper power. This effect is due to the action of the electrified body, *C*, which is said to produce electric separation *by induction*. This action will take place across a considerable distance, even if a large sheet of glass be held between *B* and *C*. When *C* is removed, the separated electricities of *B* again mingle and neutralize each other.

(*a.*) Conductors for the purposes of this and similar experiments may be made of wood, covered with tin-foil, gold leaf or Dutch leaf. They may be insulated by fastening them on top of long-necked bottles or sticks of sealing-wax, or by suspending them by silk threads.

(*b.*) Prick a pin-hole in each end of a hen's egg and blow out the contents of the shell. Paste tin-foil or Dutch leaf smoothly over the whole surface of the egg. Fasten one end of a white silk thread to the egg with a drop of melted sealing-wax, so that the egg may hang suspended with its greater diameter horizontal. Three or four such insulated conductors will be found convenient. Sometimes, it is better for each egg to have two thread supports. Place a loop or ring at the free end of each thread. When the loops are placed on a horizontal rod (*e.g.*, a piece of glass tubing), the greater diameters of the suspended eggs should lie in the same straight line. An elongated conductor like *AB* of Fig. 133 may be made by hanging two or three egg conductors, so that they are in contact, as shown in Fig. 132.

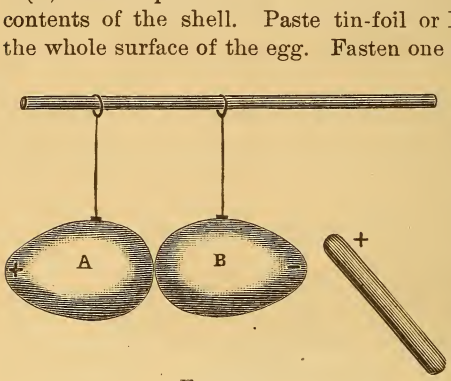


FIG. 132.

Experiment 26.—While the charged glass rod is held near the egg conductors, shown in Fig. 132, bring a pith ball electroscope near. The attraction will be evident at the free ends of the two eggs, but very little, if any, will be found at or near the point where the eggs are in contact.

333. A Neutral Line.—If an insulated conductor, bearing a number of pith ball (or paper) electroscopes, be brought near an electrified body, *C*, (Fig. 133), but not near enough for a spark to pass between them, the pith balls near the ends of the conductor will diverge, showing the presence of separated or uncombined electricity. The pith balls at the middle of the polarized conductor will not diverge, marking thus a neutral line. If *C* has a positive

charge, the charge at A will be negative and that at B will be positive, as may be shown by charging an electric pendulum and testing at A and B.

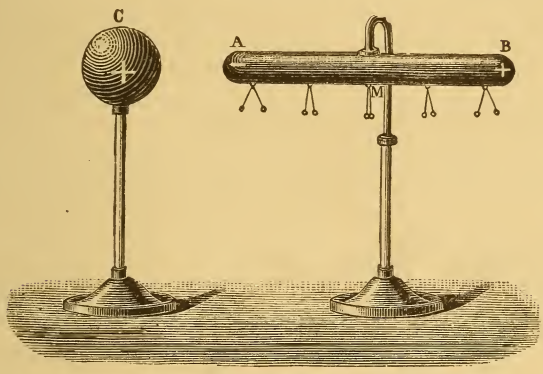


FIG. 133.

If C be removed or "discharged" by touching it with the hand, all traces of electrical separation in A B will disappear. The charged pith ball will be attracted at every point of A B.

Experiment 27.—While the charged glass rod is held near the egg conductors shown in Fig. 132, slide the loop, carrying A about 4 inches (10 *cm.*) to the left and *then* hold the rod between the two eggs. *The rod will repel one egg and attract the other.*

334. Charging a Body by Induction.—If the polarized conductor be touched with the hand, or otherwise placed in electric communication with the earth, the electricity repelled by C (Fig. 133) will escape, and the pith balls at B will fall together. The electricity at the other end will be held by the mutual attraction between it and its opposite kind at C. The line of communication with the ground being broken and the conductor

being removed from the vicinity of *C*, it will be found charged with electricity opposite in kind to that of *C*.

A body may be thus charged by induction with no loss to the inducing body. If the conductor, *A B*, be made in two parts and the parts separated, while under the inductive action of the electrified body, *C*, the two electricities can no longer return to neutralize each other, but must remain, each on its own portion of the conductor. The two parts will thus be oppositely charged.

335. Successive Induction.—If a series of insulated conductors, like the egg shells of Fig. 132, be placed in line as shown in Fig. 134, and a positively electrified

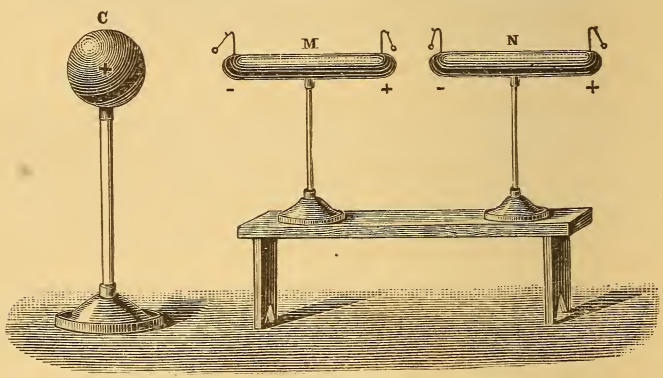


FIG. 134.

body be brought near, each conductor will be polarized. The first will be polarized by the influence of the + of *C*; the second by the influence of the + of *M*, and so on.

(*a.*) Either kind of electricity may be carried from *M* or *N* by a small insulated body, called a proof-plane (Fig. 139), to the electroscope, there tested and found to be as represented in the figure. If the conductors, *M* and *N*, be now placed in actual contact, the + of both will be repelled by *C* to the furthest extremity of *N* and the − of both will be attracted to the opposite end of *M*, near to *C*.

(*b.*) It is very plain that any body may be looked upon as a collection of many parallel series of such conductors, each molecule representing a conductor. Thus, each molecule may be polarized, + at one end and — at the other. If the body in question be a good conductor of electricity, *this polarization of the molecules is only for an instant.* The two electricities pass from molecule to molecule and accumulate at opposite ends of the body. The body is then polarized, but not the molecules of the body. On the other hand, good insulators resist this tendency to transmit the electricities from molecule to molecule and are able to maintain a high degree of molecular polarization for a great length of time. In brief, the molecules of conductors easily discharge their electricities into each other; those of non-conductors do not.

336. Polarization Precedes Attraction.— When an electrified glass rod is brought near an electric pendulum, the pith ball is polarized as shown in the figure. As the — electricity of the ball is nearer the + of the glass than is the + of the ball, the attraction is greater than the repulsion. If the pith ball be suspended, not by a silk thread but by some good conductor, the attraction will be more marked, for the + of the ball will escape to the earth through the support and, thus, the repelling component will be removed.

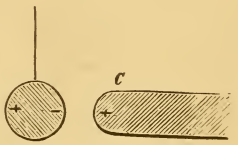


FIG. 135.

Note.—Polarization and electrification by induction explain a great many electrical phenomena.

337. Provisional Theory of Electricity.— While the real nature of electricity remains unknown, the following theory will be found convenient for classifying results already attained and suggesting directions for further inquiry. But we must not let it influence our judgment as to what is the true and full explanation of elec-

trical phenomena, which explanation may be found hereafter:

(1.) *We may assume that a neutral or unelectrified body contains equal and equally distributed quantities of positive and of negative electricity.*

(2.) *We may assume these electricities to be unlimited in amount.*

(3.) *We shall then conceive that a positively electrified body has an excess of + electricity and that a negatively electrified body has an excess of — electricity.*

(4.) *In this light, we shall see that communicating + electricity to a body is equivalent to removing an equal amount of — electricity from it, and conversely.*

338. The Electrophorus.—This simple instrument consists generally of a shallow tinned pan filled with resin, on which rests a movable metallic cover with a glass or other insulating handle. The resinous plate may be replaced by a piece of vulcanized india-rubber. The metal surface and the resinous surface touch at only a few points; they are practically separated by a thin layer of insulating air.

(*a.*) The resinous plate may be prepared by melting together equal quantities of resin and Venice turpentine and then adding a like quantity of shellac. The substances should be heated gradually and stirred together so as to prevent the forming of bubbles. Be careful that the mixture does not take fire in course of preparation. The Venice turpentine is desirable, but not necessary. For a handle, a stout wire may be soldered to the centre of the disc and covered with rubber tubing, or a piece of sealing-wax, of convenient size,

may be fastened to the disc for the purpose. A still better plan is to make the cover of wood, a little less in diameter than the resinous plate. Its edges should be carefully rounded off. For a handle, a glass rod or tube may be tightly thrust or cemented into a hole in the middle of the cover. Place tin-foil all over the cover and smooth down all rough ed es of the foil with the finger-nail or paper-folder. The wire support for a pith ball or paper electroscope may be thrust into the wood of the cover, care being taken that it touches the tin-foil.

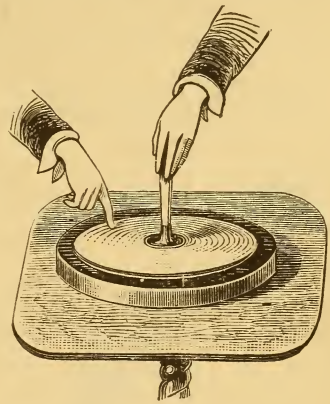


FIG. 136.

(*b.*) For an electroscope for the electrophorus, provide a bit of wire about 8 *cm.* long and bend it at right angles about 1 *cm.* from each end. Solder one of the bent arms of the wire (see Appendix B) to the upper side of the metal cover, near its edge, in such a way that the central part of the wire shall be vertical. Cut a strip of gold leaf (or Dutch metal) about 8 *cm.* long and 8 *mm.* wide. Moisten the *sides* of the free horizontal wire-arm with a little mucilage, place the middle of the gold-leaf strip over the top of the arm and bring the ends of the leaf down to a vertical position, touching each other. The mucilage will hold the leaf to the wire. When the wire support and gold leaves are electrified, the latter will diverge. When the apparatus is not in use, this electroscope may be protected by inverting a tumbler or beaker glass over it.

(*c.*) The plate is rubbed or struck with flannel or catskin and thus negatively electrified. The cover is then placed upon the resin and thus polarized by induction. If the cover be provided with a gold-leaf electroscope, the free negative electricity of the cover will cause the leaves to diverge ; the positive electricity of the cover will be "bound" on the under side of the cover by the attraction of the negative electricity of the resin. Remove the cover and the separated electricities reunite, as is shown by the falling together of the lately divergent gold leaves. Place the cover again upon the resin. Polarization is manifested by the divergence of the leaves. Touch the cover with the finger as shown in the figure; the — electricity escapes and the leaves fall. The cover is now charged positively, but its electricity is all "bound" at its under surface

and cannot cause the leaves to separate. Remove the cover by its insulating handle and the electricity, lately "bound" but now "free," diffuses itself and the leaves are divergent with + electricity. The charged cover will give a spark to the knuckle or other unelectrified body presented to it. (Fig. 137.)

339. The Electrophorus Charged by Induction.—The cover may be thus charged and discharged an indefinite number of times, in favorable weather, without a second electrifying of the resinous plate. This could not happen if the electricity of the cover were drawn from the plate. Moreover, if the charge of the cover were drawn from the plate, it would be —, and not +. There is no escape from the conclusion that the *cover is charged by induction and not by conduction.*

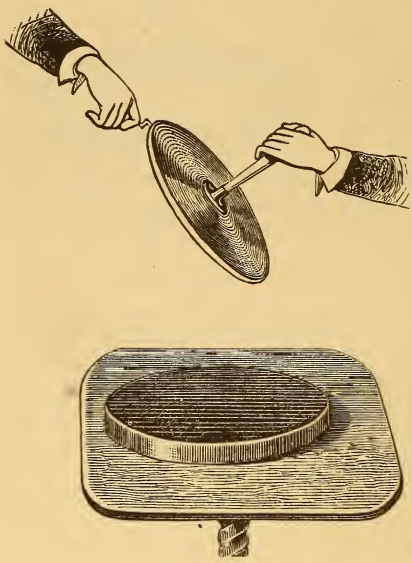


FIG. 137.

(*a.*) If the resin were a good conductor like the metal cover, its molecules would all receive + electricity from the cover and give — electricity to it. But as the resin is a poor conductor, only the very few molecules that come in actual contact with the cover at each charging have their electrical equilibrium restored. The + of the cover cannot readily pass through them to their electrified neighbors. Hence, it requires a great many placings of the cover upon the plate to discharge the resin by reconveying to it the + electricity removed at its electrification. When the cover is charged, it gives up part of its — electricity; when it is discharged, it re-

ceives this — electricity back again from the body that discharges it. As this giving and taking is neither to nor from the resin, it may be continued almost indefinitely. A Leyden jar (§ 353) may be charged with an electrophorus.

340. Whence this Energy?—At every discharge of the electrophorus, it gives a definite amount of electricity, capable of doing a definite amount of work. As this is obtained not by the expenditure of any part of the original charge, we are led to seek for *the source of this apparently unlimited supply of energy.*

"As a matter of fact, it is a little harder work to lift the cover when it is charged with the + electricity than if it were not charged, for, when charged, there is the

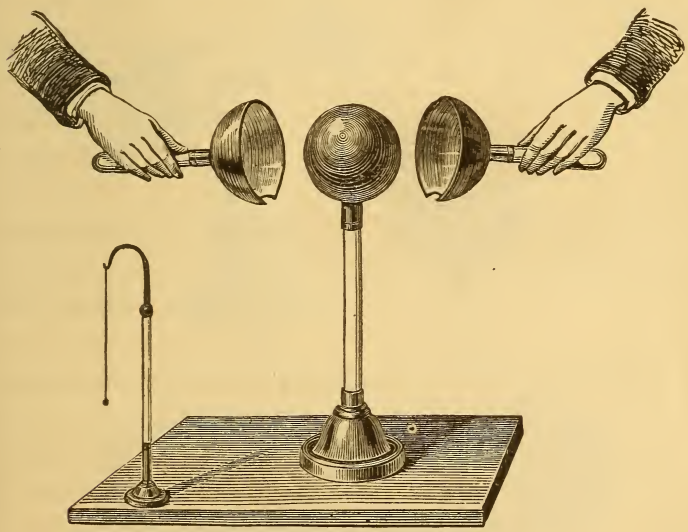


FIG. 138.

force of electric attraction to be overcome as well as the force of gravity. Slightly harder work is done at the expense of the *muscular energies* of the operator and this is

the real origin of the energy stored up in the separate charges."

Experiment 28.—Insulate a metal globe and provide it with two closely fitting hemispherical shells that have insulating handles. Electrify the globe ; bring it near the electroscope to be sure that it is electrified. Place the hemispheres upon the globe. Remove them quickly, being careful that their edges do not touch the sphere after the first separation. (Fig. 138.) Bring first one shell and then the other near the electroscope ; they are electrified. Bring the globe itself near the electroscope. *It is no longer electrified.* Delicate manipulation is needed to make the experiment successful. You will fail, perhaps, more times than you succeed. But when the experiment is successful, it is instructive. The apparatus is called Biot's hemispheres.

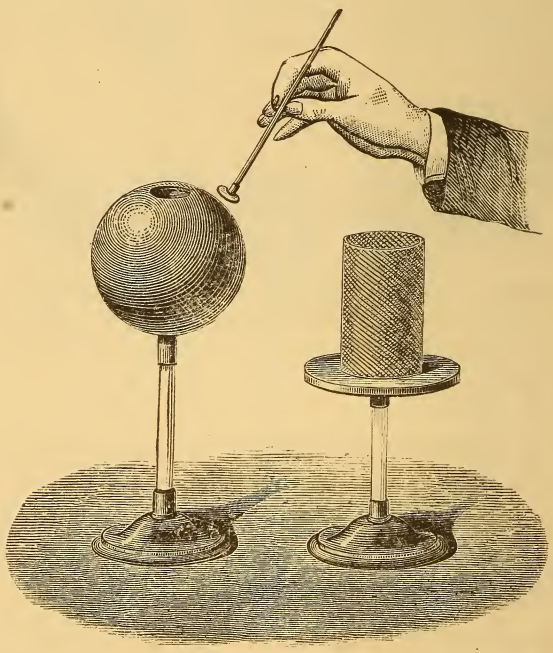


FIG. 139.

Experiment 29.—By means of a few sparks from the electrophorus, charge an insulated hollow sphere, having an orifice in the

top. Bring a proof-plane (made by fastening a disc of gilt paper to a long, thin insulating handle) into contact with the outer surface of the sphere. The proof-plane is charged by the sphere, as may be shown by bringing it near an electroscope. Discharge the proof-plane and bring it into contact with the inner surface of the sphere. Remove it carefully without allowing it to touch the sides of the orifice. Bring it to the electroscope. *It is not charged.* (Fig. 139.) An empty tin fruit can supported on a clean, dry, glass tumbler will answer for the experiment.

Experiment 30.—Make a conical bag of linen, supported, as shown in Fig. 140, by an insulated metal hoop five or six inches in diameter. Charge the bag with the electrophorus. A long silk thread extending each way from the apex of the cone will enable you to turn the bag inside out without discharging it. Test the inside and outside of the bag, using the proof-plane described above. Turn the bag and repeat the test. Whichever surface of the linen is external, *no electricity can be found upon the inside of the bag.* Nothing can be more conclusive than this.

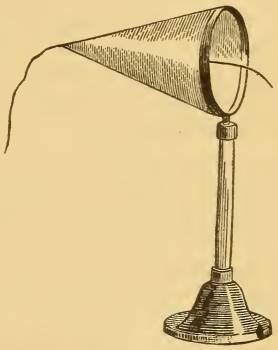


FIG. 140.

Experiment 31.—Vary the experiment by the use of a hat suspended by silk threads. Notice that the greatest charge can be obtained from the edges; less from the curved or flat surface; none from the inside.

341. A Charge Resides on the Surface.—Many experiments have been made showing that *when a conductor is electrified, the electricity passes to the surface and escapes if the body be not insulated.* A bomb-shell and a cannon ball of equal diameter will receive equal quantities of electricity from the same source. The hollow conductors commonly used in experiments with static electricity are as serviceable as if they were solid. A wooden prime conductor coated with gold-leaf is as

efficient as if it were made of solid gold. Experiment is unable to find any difference in this respect between a solid sphere of metal and the thinnest soap-bubble of the same diameter.

(*a.*) This does not apply to an electric current. A hollow wire will not conduct electricity as well as a solid wire of the same diameter. Electricity may be *drawn* to the inside of a hollow conductor by placing there an electrified, insulated body.

(*b.*) The linen bag of Experiment 30 was devised by Michael Faraday, but his most striking experiment was made with a wooden cage, measuring 12 feet each way, covered with tin-foil, insulated and charged by a powerful electric machine. He carried his most delicate electroscopes into this cage. Large sparks and brushes were darting off from every part of the outer surface, but the philosopher and his sensitive instruments within the cage failed to detect the least electric influence.

Experiment 32.—Place a carrot horizontally upon an insulating support. Into one end of the carrot, stick a sewing-needle. Bring the electrified glass rod near the point of the needle without touching it. The — electricity of the carrot quietly escapes from the point to the rod and the carrot is charged with the + electricity that remains.

342. Density.—Experiments show that when a spherical conductor is charged, the electricity is evenly distributed over the surface, provided no other electrified body be near to affect the distribution by induction. The electric density (or number of electrical units per unit of area) is the same at every point. Experiments on an elongated cylinder, like the prime conductor of the electric machine, show that the density is greater at the ends. On an egg-shaped conductor, like that shown in Fig. 141, the density is greatest at the smaller end. *In general, the electric density is very great at any pointed part of a charged conductor.*

This density at a point may become so great that the electricity will escape rapidly and quietly, the air particles

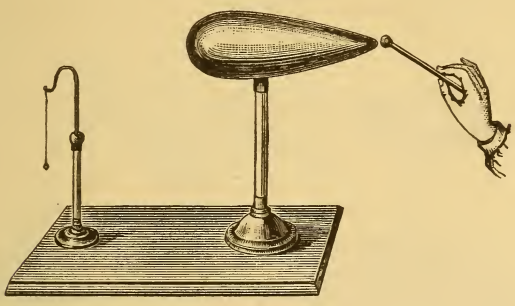


FIG. 141.

quickly carrying off the charge by convection. This explains the effect of pointed conductors, which plays so important a part in the action of electric machines. This property will be illustrated in several of the experiments of § 371. It is fundamental to the quiet action of lightning rods.

343. Electric Machines.—Machines have been made for developing larger supplies of electricity more easily than can be done with a rod of glass or sealing-wax or with the electrophorus. Each of them consists of one part for producing the electricity and another part for collecting it.

344. The Plate Electric Machine.—This instrument is represented in Fig. 142. It consists of an insulator (or electric), a rubber, a negative and a positive or prime conductor. The electric is a glass (or ebonite) plate, *A*, generally one, two or three feet in diameter. This plate has an axis, *B*, and handle, *C*, and is supported upon two upright columns. The rubber, *D*, is made of two cush-

ions of silk or leather, covered with amalgam (see § 302, *a*). They press upon the sides of the plate and are supported

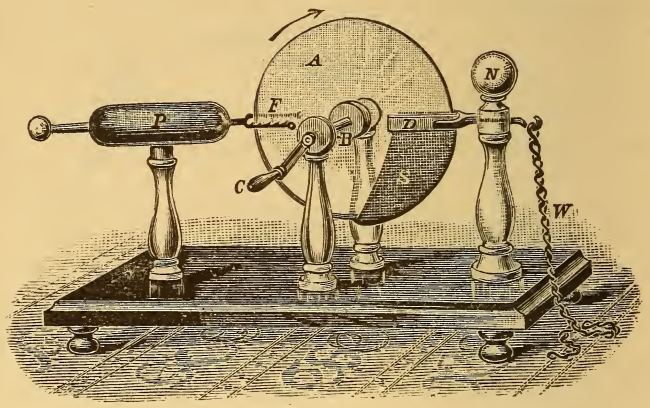


FIG. 142.

from the negative conductor, with which they are in electric connection. The negative conductor, *N*, is supported upon an insulating column and, when only positive electricity is desired, is placed in electrical connection with the earth by means of a chain or wire, *W*. The prime conductor, *P*, is insulated. One end of the prime conductor terminates in two arms, *F*, which extend one on either side of the plate. These arms, being studded with points projecting toward the plate, are called *combs*. The teeth of the combs do not quite touch the plate. A silk bag, *S*, is often supported so as to enclose the lower part of the plate. All parts of the instrument except the teeth of the combs are carefully rounded and polished, sharp points and edges being avoided to prevent the escape of electricity as already explained. This avoiding of points and edges is to be regarded in all apparatus for use with electricity of high potential.

(*a.*) The pupil may make a plate machine without much expense. A glazier will cut for him a disc of plate glass, possibly from a fragment on hand. The edges of this disc may be rounded on a wet grindstone. A hole may be bored in the middle with a round file kept moistened with a solution of camphor in turpentine. The conductors, *N* and *P*, may be made of wood covered with gold-foil or Dutch leaf and supported on pieces of stout glass tubing. The prime conductor may well have two such supports. The arms may consist of two stout wires thrust into the end of a prime conductor, their free ends being provided with knobs of lead or other metal. The combs may be made by soldering pin points to one side of each arm. See that the gold-foil makes actual contact with the metal arms. See that all metal parts except the pin points are polished smooth. The columns that support the plate may be made of seasoned wood. The part of the handle to which the hand is applied may be made of glass or insulated by covering it with rubber tubing.

345. Operation of the Plate Machine.—The plate is turned by the handle. Electric separation is produced by the friction of the rubbers. The + electricity of the rubber and negative conductor passes to the plate; the — electricity of the plate passes to the rubber and negative conductor. The part of the plate thus positively charged passes to the combs of the prime conductor. The + of the plate acts inductively upon the prime conductor, polarizes it, repels the + and attracts the — electricities. Some of the — electricity thus attracted streams from the points of the combs against the glass, while some of the + electricity of the glass escapes to the prime conductor. This neutralizes that part of the plate, or restores its electric equilibrium, and leaves the prime conductor positively charged. As each successive part of the plate passes the rubber, it gives off — electricity and takes an equal amount of + ; as it passes between the combs it gives off its + electricity and takes an equal amount of —. The

rubber and negative conductor are kept in equilibrium by means of their connection with the earth, "the common reservoir." As the plate revolves, the lower part, passing from N to P, is positively charged; the upper part, passing from P to N, is neutralized. If negative electricity be desired, the ground connection is changed from N to P and the charge taken from N.

346. The Dielectric Machine.—This instrument is represented in Fig. 143. Two plates of vulcanite (ebonite), A and B, overlap each other without touching and revolve in opposite directions. The upper plate is made to revolve much more rapidly than the lower by means of the pulleys shown at the right of the figure. The prime conductor and the axes of the two plates are carried by two insulating pillars. From the prime conductor, a comb is presented to the upper part of the upper plate. Another comb is presented to that part of A which is overlapped by the upper part of B. This comb is connected by a universal joint at e with a discharging rod and ball, which may be brought near the end of the prime conductor or turned away from it. The rubbers and the lower comb are to be in electrical communication with the earth. The general arrangement is clearly set forth in the figure.

347. Operation of the Dielectric Machine.—The plate, B, is turned directly by the handle and the plate, A, indirectly by the aid of the pulley. The plate, B, is negatively electrified by friction with the rubber and thus acts by induction upon the lower part of A, which is thus polarized. The + of this part of A is

bound by the attraction of the — of B, while the — of A is repelled, escapes by the lower comb and is replaced by + from the earth through the lower comb and its ground connection. This part of A, thus positively charged, is soon removed from the inducing body and the + charge, *bound* by B, is set free. It then comes to the upper comb, polarizes it and the prime conductor and exchanges some of its own + for an equal amount of — from the prime conductor. This neutralizes that part of the upper plate and leaves the prime conductor positively charged. As each successive part of A passes the lower comb, it gives off — electricity and takes an equal amount of + ; as it passes the upper comb, it gives off + electricity and receives an equal amount of —. The charge of B is continually maintained by friction with the rubber. When the discharging rod and ball are brought near the prime conductor, as shown in the figure, a rapid succession of sparks is produced, owing to the recombination of the separated electricities. If another body is to be charged from the prime conductor, the ball and rod may be turned aside. The efficiency of this machine is greater than that of the plate

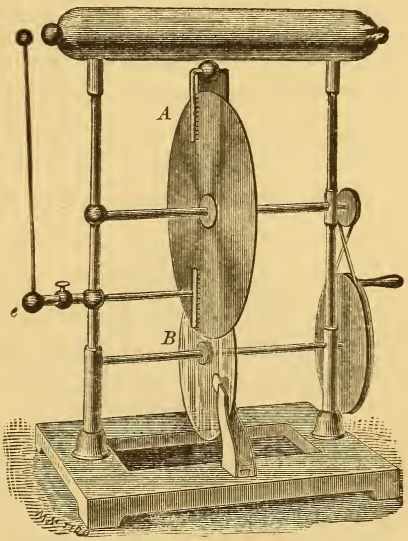


FIG. 143.

or cylinder machine. It is less affected by atmospheric moisture and is more compact, but the vulcanite plates seem to deteriorate with use. They should be washed occasionally with ammonia water and rubbed with paraffin oil. Machines of similar construction, but having glass plates, are made.

348. The Holtz Electric Machine.—This instrument is represented in Fig. 144. It contains two thin, circular plates of glass, the larger of which is held fast by two fixed pillars. The smaller plate revolves rapidly very near it. There are two holes in the fixed plate near the extremities of its horizontal diameter. To the sides of these openings are fastened paper bands called *armatures*. The armatures point in a direction opposite to that in which the revolving plate moves. Opposite these armatures and separated from them by the revolving plate, are two metallic combs, connected respectively with the two knobs and Leyden jars shown in the front of the picture. One of these knobs is carried by a sliding rod so that their distance apart is easily adjusted. When this machine works well, it gives results superior to either of those previously mentioned. It is, however, peculiarly subject to atmospheric conditions and is generally considered extremely capricious.

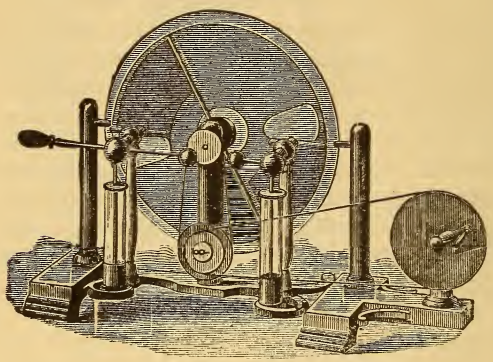


FIG. 144.

349. Action of the Holtz Machine.—To understand the action of this machine requires careful attention. The knobs are placed in contact and a small initial charge is given to one of the armatures by some charged body, as a piece of vulcanite or a glass rod. The handle is then turned, the effort necessary to keep up the motion increasing rapidly. The knobs are then separated and a series of discharges takes place between them.

(*a.*) Suppose a small + charge to be imparted at the outset to the right armature. This charge acts inductively across the revolving plate upon the metallic comb, repels + electricity through it and leaves the points negatively electrified. They discharge negatively electrified air upon the front surface of the movable plate; the repelled + charge passes through the brass rods and balls and is discharged through the left comb upon the front side of the movable disc. Here it acts inductively upon the paper armature, causing that part of it which is opposite itself to be negatively charged and repelling a + charge into its farthest part, *viz.*, into the armature. This, being bluntly pointed, slowly discharges a + charge upon the *back* of the movable plate. When the plate is turned round, this + charge on the back comes over from the left to the right side and, when it gets opposite the comb, increases the inductive effect of the already existing + charge on the armature and, therefore, repels more electricity through the brass rods and knobs into the left comb. Meantime the — charge, which we saw had been induced in the left armature, has in turn acted on the left comb, causing a + charge to be discharged by the points upon the front of the plate and, drawing electricity through the brass rods and knobs, has made the right comb still more highly —, increasing the discharge of negatively electrified air upon the front of the plate, neutralizing the + charge which is being conveyed over from the left. These actions result in causing the top half of the moving disc to be positively electrified on both sides and the bottom half of the disc to be negatively electrified. The charges on the front serve, as they are carried round, to neutralize the electricities let off by the points of the combs while the charges on the back, induced respectively in the neighborhood of each of the armatures, serve, when the rotation of the plate conveys them round, to increase the inductive influence of the charge on the other armature. Hence, a

very small initial charge is speedily raised to a maximum, the limit being reached when the electrification of the armatures is so great that the loss of electricity at their surface equals the gain by convection and induction.

Note.—Other forms of electric machines are made. One of the latest of these, known as the Toepler-Holtz, is very compact and efficient and remarkably free from the limitations of atmospheric conditions. It may be described as a continuously acting electrophorus (§ 227). A very good one may be bought for $25 or more. One should be provided for the school *in some way* if possible. Any electrical machine should be free from dust and perfectly dry when used. It should be warmer than the atmosphere of the room, that it may not condense moisture from the surrounding air. The drier the atmosphere, the better will be the action of the machine.

EXERCISES.

1. How can you show that there are two opposite kinds of electricity?

2. How would you test the *kind* of electricity of an electrified body?

3. Quickly pass a rubber comb through the hair and determine whether the electricity of the comb is positive or negative.

4. Why do we regard the two electric charges produced simultaneously by rubbing together two bodies as being of opposite kinds?

5. Why is it desirable that a glass rod used for electrification be warmer than the atmosphere of the room where it is used?

6. Electrify one insulated egg-shell conductor (§ 332, *b*). Bring it near a second conductor but not in contact with it. Touch the second egg-shell with the finger. (*a.*) Experimentally, determine whether the second egg-shell is electrified or not. (*b.*) If you find that it is, what word explains the method of charging? (*c.*) If the second egg-shell is charged, will its potential and the potential of the first be of the same or of opposite signs?

7. (*a.*) In § 323, *b*, it is directed that an electrified body be brought "near" the knob of the gold-leaf electroscope. Why not *touch* the knob with the charged body? (*b.*) Why do not the gold leaves diverge immediately after touching the knob with the finger as there directed? (*c.*) If the electrified body being tested had a + charge, is the charge of the gold leaves + or −? Explain.

8. (*a.*) What is a proof-plane? (*b.*) An electroscope? (*c.*) Describe one kind of electroscope. (*d.*) Another kind.

9. (*a.*) Define *electrics*, *conductors* and *insulators*. (*b.*) Explain electric induction.

10. (*a.*) If a metal globe suspended by a silk cord be brought near the prime conductor of an electric machine in action, feeble sparks will be produced. Explain. (*b.*) If the globe be held in the hand, stronger sparks will be produced. Explain.

11. Twist some tissue paper into a loose roll about six inches long. Stick a pin through the middle of the roll into a vertical support. Present an electrified rod to one end of the roll and thus cause the roll to turn about the pin as an axis. Give this piece of scientific apparatus an appropriate name.

12. (*a.*) Prepare two wire stirrups, *A* and *B*, like those shown in Fig. 121 and suspend them by threads. Electrify two glass rods by rubbing them with silk and place them in the stirrups. Bring *A* near *B*. Notice the repulsion. (*b.*) Repeat the experiment with two sticks of sealing-wax that have been electrified by rubbing with flannel. Notice the repulsion. (*c.*) Place an electrified glass rod in *A* and an electrified stick of sealing-wax in *B*. Notice the attraction. Give the law illustrated by these experiments.

13. Two small balls are charged respectively with + 24 and − 8 units of electricity. With what force will they attract one another when placed at a distance of 4 centimeters from one another?

Ans. 12 dynes.

14. If these two balls are then made to touch for an instant and then put back in their former positions, with what force will they act on each other? *Ans.* Repulsion of 1 dyne.

Experiment 33.—Hang a negatively charged pith ball inside a dry glass bottle. Bring an electrified glass rod to the outer side of the bottle. The pith ball will rush to the side of the bottle nearest the rod because of the attraction between the opposite electricities.

Experiment 34.—Paste a piece of tin-foil, two or three inches square, on the middle of each face of a pane of glass. Hold a finger on one of the metallic coats while the other coat is held, for a short time, in contact with the prime conductor of an electric machine in operation. Remove the pane and place it on edge without touching both coats at the same time. Although both coats are oppositely charged (§ 334), they may be touched in succession without any shock. When both are touched at the same time, the shock is greater than would have been received from the prime conductor by which *this condenser* was charged.

350. Condensation of Electricity. — Two suspended pith balls oppositely charged attract one another across the intervening air. They attract mutually even when a plate of glass is held between them although neither the balls nor their electric charges can pass through the glass. In the case of the pane of glass with its two tin-foil coats, or in the similar case of two metallic plates, *A* and *B*, separated by a layer of dry air or other non-conductor, *C*, as shown in Fig. 145, the two charges are "bound," each by the attraction of its opposite on the other side of the pane. It is found that two such coats may be charged much more strongly than either one could be if the opposite coat were wanting. If a third plate like *B*, *but hav-*

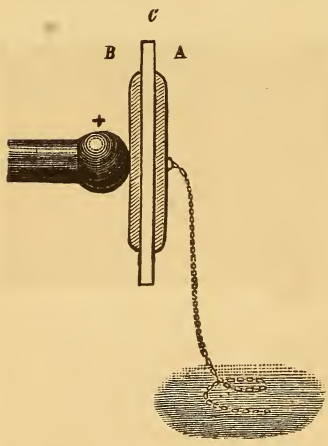


FIG. 145.

ing no opposite plate like A, be connected with *B* by a copper wire and the middle of the wire brought into contact with the prime conductor, nearly the whole charge will go to *B* and very little to the third plate. *The capacity of a charged conductor is greatly increased by bringing it near a second charged conductor oppositely charged.* Its capacity being thus increased, a greater quantity of electricity must be put into it to raise it to as high a potential. Such a method of increasing the quantity of electricity that a conductor may receive without raising its potential is called the condensation or accumulation of electricity.

351. Electric Condensers.—An apparatus for collecting a large quantity of electricity at a moderate potential, as just described, is called an electric condenser.

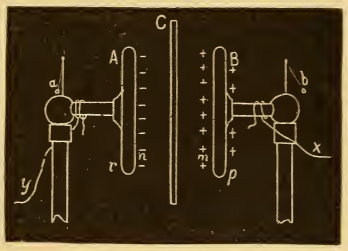


FIG. 146.

(*a.*) Let *A* and *B*, Fig. 146, represent two insulated metallic plates about six inches in diameter, separated by *C*, a plate of glass somewhat larger. Let each metallic plate have an electric pendulum, *a* and *b*. Remove *A* and connect *B* with the conductor of the electric machine, by means of the wire, *x*. The divergence of *b* shows the presence of free electricity. Connect *A* with the ground by the wire, *y*, and place it in position as represented. By the inductive influence of *B*, the − electricity of *A* is drawn to the surface, *n*, while the + escapes by *y*. But this − electricity at *n* attracts the + of *B* largely to the surface *m* and holds it there as *bound* electricity, thus increasing the electrical density at that surface. This change is shown by less divergence of *b*. Consequently, *B* can receive more electricity from the machine, which will, in turn, attract more − electricity to *n*. This further supply will, in

turn, bind more of the + electricity of B at m. In this way, a large quantity of + electricity may be accumulated at m and a large quantity of − at n. This accumulation may thus go on until the potential at the surface, p, is equal to that of the machine, as it was when A was absent. Interrupting communication by x and y, both plates are charged. The vertical pendulum, a, shows no *free* electricity, the electricity of A being all bound at n; the pendulum at b shows some free electricity, although the greater part of the electricity of B is bound at m. Remove A and B from each other and the bound electricity of each is set free and both a and b fly out as the discs are separated. The pith balls thus seem to indicate that the discs are more highly electrified when they are thus separated, but no additional charge has been given to either A or B. The fact is that *while B was near A, the capacity of B was largely increased. On moving it away from A, its capacity was diminished and the same quantity of electricity electrified it to a higher potential than before. The presence of an earth connected plate near an insulated conductor largely increases the electric capacity of the latter, enabling it to condense electricity upon the surface nearest the opposing plate, at which surface the electrical density becomes very great.*

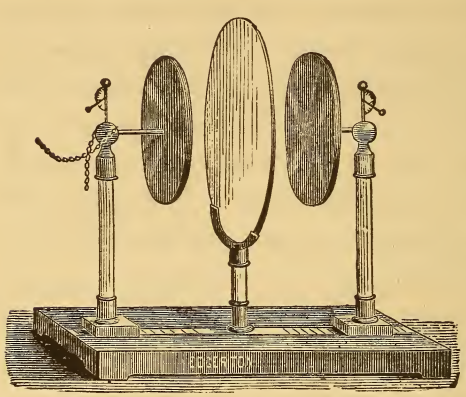


FIG. 147.

(*b.*) If A and B are pushed up close to C, the decrease of distance will work an increase of the inductive action and a still larger quantity may be accumulated in the plates. *Thus, the capacity of a condenser depends, in part, upon the nearness of the plates to each other.*

352. Dielectrics and Specific Inductive Capacity.—Substances that permit inductive electric influences to act across or through them as just described are called *dielectrics*. All dielectrics are insulators, but

equally good insulators are not always equally good dielectrics. Glass is a better dielectric than ebonite and ebonite is better than air. The capacity of a condenser is greater when the dielectric is glass than it is when the dielectric is air. *The ratio of the capacity in the former case to the capacity in the latter case is called the specific inductive capacity (or specific inductivity) of glass.* Air (at 0° C. and 760 *mm.*) is taken as the standard, its specific inductive capacity being unity.

(*a.*) The old idea that electric induction is "action at a distance" is wholly disproved by the fact that different substances have different specific inductive capacities, for it is evident that the dielectric itself is concerned in the process. Otherwise, all media would allow induction to take place across them with equal facility.

(*b.*) The specific inductivity (sometimes called dielectric capacity) assigned to various substances by different observers varies widely. Gordon gives the following results:

Air.....1.00	Ebonite.....2.284	Shellac.....2.74
Paraffin (solid).1.9936	Gutta percha..2.462	Glass, from....3.013
India rubber..2.22	Sulphur.....2.58	" to.....3.258

Schiller gives the specific inductivity of white mirror glass as 5.88 to 6.34.

353. The Leyden Jar.—The most common and, for many purposes, the most convenient form of condenser is the Leyden jar. This consists of a glass jar, coated within and without for about two-thirds its height with tin-foil, and a metallic rod, communicating by means of a small chain with the inner coat and terminating above in a knob. The upper part of the jar and the cork which closes the mouth of the jar and supports the rod are generally coated with sealing-wax or shellac varnish to lessen the deposition

FIG. 148.

of moisture from the air. The inner coat represents the collecting plate, B; the glass jar, the insulating plate, C; the outer coat, the condensing plate, A, of Fig. 146.

(*a.*) Select a candy or fruit jar of greenish glass; paste tin-foil within and without, as above described, using flour paste; thrust a wire through a dry cork; bend the wire so that, when the cork is in its place, the wire shall touch the tin-foil on the inside of the bottle without tearing it; solder the upper end of the wire to a smooth button or thrust it into a lead bullet; charge *your Leyden jar* with a few sparks from the electrophorus and take a shock.

354. Charging the Leyden Jar.—To charge the jar, hold it in the hand, as shown in Fig. 149, and bring the knob near the prime conductor of an electrical machine that is in action or into contact with it.

(*a.*) The + charge thus developed on the inner coat acts inductively through the glass, repelling the + electricity which escapes through the hand to the earth and binding its — electricity to the surface in contact with the glass. This "bound" negative electricity of the outer coat, in turn, binds the positive of the inner coat, which then may receive a further charge and so on. The inner coat will receive a much greater quantity of electricity than it possibly could were it not for the attraction of its opposite on the outer coat. If, instead of holding the outer coat in the hand, the jar be supported upon a pane of glass so that the repelled electricity of the outer coat cannot escape, the jar cannot be very intensely charged.

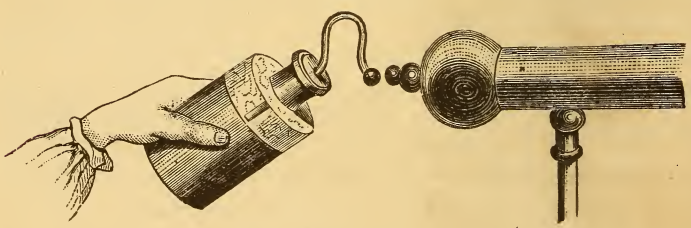


FIG. 149.

(*b.*) Thus we see again that the capacity of a conductor is greatly increased when it is placed near a conductor charged with the oppo-

site kind of electricity. Its capacity being increased, it can receive a greater quantity of electricity without any increase of potential. Of course, the potential of the charged jar cannot exceed that of the prime conductor or other charging body.

355. Discharging the Leyden Jar.—If the jar be of good glass, dry and free from dust, it will retain its charge for hours. But if a path be provided by which the opposite and mutually attracting electricities can flow together, they will do so and the jar will be instantaneously and almost completely discharged. The jar might be discharged by touching the knob with the finger, the separated electricities coming together through the person of the experimenter and the earth. In this case, the experimenter will feel a "shock." If the charge be intense, the shock will be painful or even dangerous. It is better to use a "discharger," two forms of which are represented in Fig. 150. This consists of two metal arms hinged together, bearing knobs at their free ends and carried by insulating handles. The outer coat of the jar should be touched first. Why?

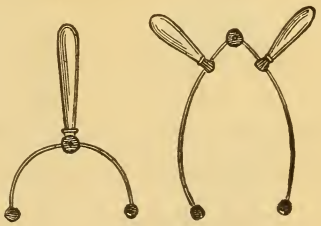


FIG. 150.

(*a.*) A good discharger may be made by passing a piece of stout, copper wire, about a foot long, through a piece of rubber tubing and providing a metal knob for each end of the wire. The flexibility of the wire avoids the necessity for a hinged joint.

356. The Residual Charge.—If a Leyden jar be charged, discharged and left for a little time to itself, it will be found that a small, second spark can be obtained.

There is a residual charge which seems to have soaked into the glass. The return of the residual charge is hastened by tapping the jar. The amount of the residual charge varies with the time that the jar has been left charged ; it also depends on the kind of the glass of which the jar is made. (See Appendix J.)

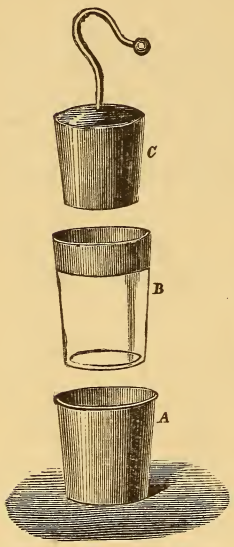


FIG. 151.

357. The Leyden Jar with Movable Coats.—This piece of apparatus is represented by Fig. 151. The upper part of the glass jar, *B*, is coated with shellac varnish. The three parts being placed together in proper order, *B* within *A* and *C* within *B*, the jar is charged in the usual manner. The inner coat, *C*, is then removed with a glass rod and touched with the hand to discharge it fully. *B* is then lifted out from *A* and the outer coat fully discharged. The three parts are then put together again and found to be able to give nearly as strong a spark as at first. This seems to indicate that the charge rests upon the surfaces of the glass rather than upon the surfaces of the coats. If, when the charged jar is in pieces, the thumb be placed on the outer surface of the glass and the forefinger of the same hand on the inner surface, a very slight shock is perceptible. The oppositely charged glass molecules that come into actual contact with thumb and finger respectively are discharged. By changing the position of the thumb and finger, successive little shocks may be felt as successive portions of the inner and outer surfaces of the glass are discharged. The inner coat furnishes a means for the simultaneous discharge of the inner layer of glass molecules ; the outer coat does the same for the outer layer of glass molecules. Thus all or nearly all of the electrified glass molecules may be discharged simultaneously instead of successively.

358. The Leyden Battery.—The effect that may be produced with a Leyden jar or other condenser depends

upon the size of the coats, the thinness and the inductive capacity of the glass. But a large jar is expensive and requires great care; thin glass is liable to perforation by

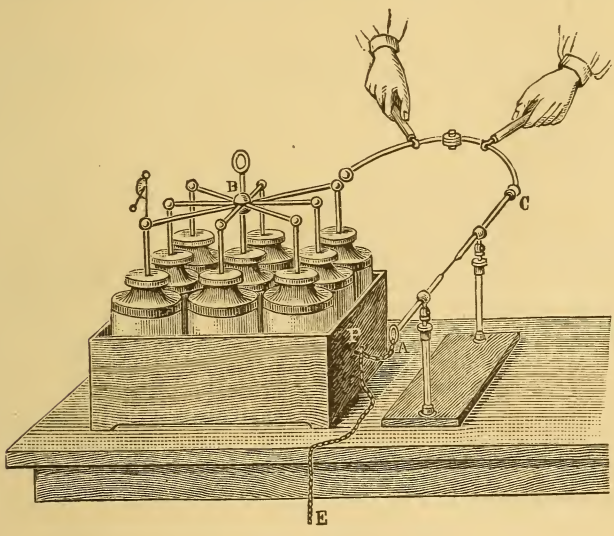


FIG. 152.

the condensed and strongly attracting electricities of its two coats. To obviate both of these difficulties, a collection of jars is used. When their outer coats are in electric communication, which may be secured by placing them in a tray the bottom of which is covered with tin-foil, and their inner coats are connected by wires or metal strips passing from rod to rod, or from knob to knob, the apparatus is called a Leyden or electric battery. "Toughened glass" is less easily pierced than ordinary glass. Hence, Leyden jars made of it may be made thinner and, consequently, will hold a greater charge than otherwise. The battery is charged and discharged in the same way as a single jar. Great care is needed, for if the discharge

were to take place through the human body the result would be serious and possibly fatal. The "universal discharger," as employed with the Leyden battery, is shown at AC in Fig. 152. (See Exp. 56.)

(*a.*) The horizontal rods of the universal discharger may be supported by passing them through corks in the mouths of two bottles. When a table is wanted for the support of bodies to be operated upon by the discharge, it may be made by placing a small plate of glass upon the open mouth of a bottle of the same height as those that carry the rods and placing the third bottle between the other two.

359. The Farad.—The farad is the capacity of a condenser that will be raised to a potential of one volt by a charge of one coulomb of electricity (§§ 382, 387). Such a condenser would be too large to be constructed. *The micro-farad* (=0.000001 farad) *is, therefore, chosen as the practical unit of electrical capacity.* The capacity of three miles of an Atlantic cable is about one micro-farad. A micro-farad condenser contains about 3,600 square inches of tin-foil. A farad equals 10^{-9} of an absolute unit of capacity (§ 330). See Appendix M (5).

(*a.*) A coulomb in a farad gives a volt.

$$\text{Farads} = \frac{\text{Coulombs}}{\text{Volts.}}$$

360. Submarine Cable Condensers.—An ocean cable forms a condenser, the water forming the outer coating; the conducting wire, the inner coating; while the insulating layers of gutta-percha correspond to the glass of the Leyden jar. When, for example, one end of a submerged cable is connected to the + pole of a powerful battery, + electricity flows into it. Before any signal can be received at the other end, enough elec-

tricity must flow in to charge the cable to a considerable potential, an operation which may, in the case of long cables, require some seconds. It is a serious obstacle to signalling with speed through the Atlantic cables.

(*a.*) Imagine a mile of insulated cable wire to be coiled up in a tub of water (Fig. 153), one end, *N*, being insulated. The other end is joined up through a long coil galvanometer, *G*, to the + pole of a large battery, whose — pole is joined by a wire to the water in the tub. As soon as this is done, the needle of the galvanometer will show a violent deflection, + electricity rushing through it into the interior of the cable and a — charge being accumulated on the outside of it where the water touches the gutta-percha. The flow will go on, though diminishing, until the cable is fully charged, taking, perhaps, an hour. Now remove the battery and close the circuit. The charge in the cable will rush out through the galvanometer, which will show an opposite deflection. The charge will continue "to soak out" for a long time.

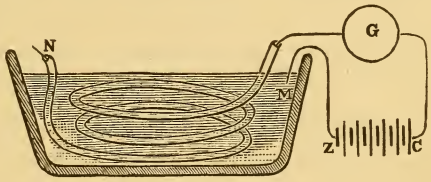


FIG. 153.

361. Modes of Discharge.—An electrified conductor may be discharged in at least three ways, *viz.*, by the *disruptive* discharge, by the *convective* discharge and by the *conductive* discharge. The discharge in any of these ways is accompanied by a transformation of energy. Sound, light, heat, chemical action and other phenomena are produced.

Experiment 35.—Present a knuckle of the hand or a metal knob to the prime conductor of an electric machine and "draw sparks" therefrom. (See Fig. 169.) For short distances, *the spark* is straight. If the distance be made somewhat greater, the spark takes a sinuous and forked form as though floating dust particles served as stepping-stones and rendered a crooked path the easiest. If the charge be

very powerful, the spark will take the zigzag form so familiar in the lightning-stroke. When the machine is vigorously worked in the dark, the apparently continuous discharge into the air produces a luminous appearance at the ends of the conductor. This appearance, known as a *brush*, may be improved by holding a large, smooth, metal globe at a distance a little too great for the passage of a spark. When the discharge takes place from the rounded end of a wire extending from the conductor, a quiet, phosphorescent *glow*, as shown in Fig. 154, will often appear at and near the end of the wire.

FIG. 154.

362. The Disruptive Discharge.—A discharge of electricity taking place suddenly through a non-conductor is called a disruptive discharge, *e.g.*, the spark and brush drawn from an electric machine in action. The glow is either a continuous discharge or one of exceedingly small period. Perhaps, it is a high order of convective discharge.

Experiment 36.—Attach a pointed wire to the prime conductor of the electric machine. The flame of a candle held near will be blown away, as shown in Fig. 155. If the candle be placed upon the prime conductor and a pointed conductor be held in the hand near the candle, the flame will still be blown away.

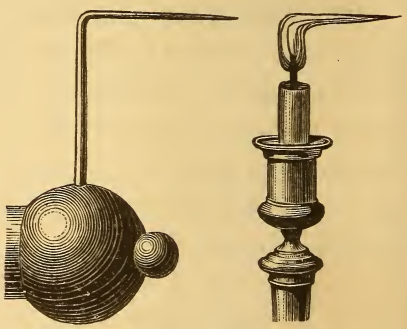


FIG. 155.

363. The Convective Discharge.—When electricity of high potential accumulates with so great a density as to electrify the neighboring particles of air which, driven by electric repulsion, fly off carrying

part of the charge with them, we have what is called the convective discharge. Such discharges are best manifested in gases at low pressure, in tubes exhausted by an air-pump. (Exp. 70.)

364. The Conductive Discharge.—The flow of a continuous current of electricity constitutes the conductive discharge. When electricity flows through a wire from the prime conductor of an electric machine to the rubbers or from the positive pole of a voltaic cell or battery to the negative, we have a conductive discharge. It will be considered in the section especially devoted to voltaic electricity.

365. Atmospheric Electricity.—The phenomena of atmospheric electricity are of three kinds:

1. A continual slight electrification of the air, best observed in fair weather.
2. The familiar phenomena of thunder storms.
3. The Aurora Borealis.

366. The First Kind.—During fair weather, the air above the surface of the earth is usually electrified positively, a negative electrification being extremely rare. In stormy weather, it is more often — than + and frequently changes from one kind to the other several times in an hour. The higher up we go to observe the usual + electricity of the air, the higher its potential is found to be. The evaporation of water by the sun's heat and the friction of moving masses of air probably contribute to the presence of atmospheric electricity.

367. Thunder Storms.—We have already seen (§ 341) that a solid conductor can not be charged through-

out its substance, the charge residing upon the surface. The same is true of liquids, but aëriform bodies may be charged bodily, the individual molecules being so much more widely separated. Dry air being a poor conductor, the air particles discharge their electricity into each other slowly and with difficulty. The electricity thus prevented from accumulating has a low potential and, hence, gives few manifestations of its presence. The minute particles of water floating in the air being better conductors than the air itself become more highly charged. As they fall and unite, the potential of their charges increases.

(*a.*) "Suppose eight small drops to join into one. That one will have eight times the quantity of electricity distributed over the surface of a single sphere of twice the radius and, therefore, of twice the capacity (for the electrical capacities of spheres are proportional to their radii) of the original drops." The capacity being thus increased only two fold while the quantity is increased eight fold, the potential becomes four times as great. Thus the potential of a cloud may rise by the union of electrified drops.

368. Lightning.—When an electrified cloud floats over the earth, separated from it by a layer of insulating air, the inductive influence of the cloud renders the ground beneath oppositely electrified. Then the cloud, ground and insulating air correspond respectively to the inner and outer coatings and the insulating glass of a Leyden jar. As the charge of a Leyden jar may be made so intense that the mutual attraction of the separated electricities will result in their rushing together and thus piercing the jar (§ 358), so the charge of a cloud may become sufficiently intense to overcome the resistance of the air and a lightning stroke ensues. Two clouds charged

with opposite electricities may float near each other. Then they, with the intervening air, may be looked upon as constituting a huge Leyden jar. Thus, we may see the lightning leaping from cloud to earth, or from cloud to cloud. Such electric sparks are sometimes more than a mile in length, showing a difference of potential greater than that of 3,000,000 Daniell's cells. The duration of the spark or flash is not more than 0.00001 of a second. The danger from any lightning stroke has passed when we hear the crash. The identity of lightning with electricity, though long suspected, was first proved by Franklin's famous kite experiment.

Experiment 37.—Bring the point of a knife-blade near the conductor of an electric machine in operation and *notice the instant cessation of sparks.* The quiet passage of electricity from the earth neutralizes the charge of the conductor and restores the electric equilibrium. In the same way, a lightning-rod tends to restore the electric equilibrium of the cloud and prevent the dangerous discharge.

369. Lightning-Rods.—The value of lightning-rods depends upon the tendency of electricity to follow the best conductor and upon the effect of pointed conductors upon electrical density (§ 342). The lightning-rod should, therefore, be made of a good conductor; copper is better than iron. It should terminate above in one or more points, tipped with some substance that may be corroded or fused only with extreme difficulty. Platinum and iridium are metals that satisfy these conditions very well. The rod should extend above the highest point of the building in order to offer the electricity the easiest path to the ground. It is important to have each projecting part of the building, as chimneys, towers and

gables, protected by a separate rod. All metal work about the roof or chimneys should be connected with the rod. The rod should afford an unbroken connection; the joints, if there be any, should be carefully made. The rod should terminate below in water, or in earth that is *always* moist. It is well to connect it with underground water-pipes when possible or with a large metal plate. *Personal attention* should be given to this matter when the rod is put up as, being under ground and out of sight, this part of the rod is not easily inspected subsequently. *A rod having a blunted tip, a broken joint or terminating in dry earth is more dangerous than no rod at all. Lightning-rod insulators are undesirable.*

(*a.*) The greatest value of a lightning-rod is due to its quiet work in the *prevention* of the lightning stroke. For this quiet but very valuable service, few persons ever give the rod any credit. Every leaf of the forest and every blade of grass is a pointed conductor acting in the same way.

(*b.*) There is some question as to the space protected by a rod, but the following is a good rule: The protected space is a cone having its apex at the tip of the rod and having a base the radius of which is equal to the height of the cone.

370. The Aurora Borealis.—The aurora borealis or "northern light" is frequently seen in northern regions; beyond the Arctic circle it is of almost nightly occurrence. Sometimes its streamers of light radiate like the ribs of a fan or form an arch across the northern sky, as shown in Fig. 156. But, as seen in this country, it more often appears as a few streamers of a pale tint. Similar lights are seen in south polar regions and are called *aurora australis.*

The atmosphere, in its upper strata, is highly rarefied and conducts electricity as do the rarefied gases in Geissler

tubes (Exp. 70). There is little doubt that the aurora is due to electric discharges in this rarefied air. The appear-

FIG. 156.

ance of an aurora is generally accompanied by a "magnetic storm" or irregular disturbance that affects all of the compass needles over a considerable part of the earth.

371. Apparatus and Experiments. — It is neither necessary nor very desirable that all of the following experiments be performed. Several of them involve the same principle; but one teacher may have one piece of apparatus and another, another piece. Additional experiments may be found in "The First Principles of Natural Philosophy," pp. 174–176.

Experiment 38.—Place a tin plate containing a handful of small bits of tissue paper upon the prime conductor of an electric machine. Work the machine and thus produce an imitation snow storm.

Experiment 39.—The "metallic plates and dancing images" are represented in Fig. 157. The images are made of pith. The upper plate is in communication with the prime conductor; the lower one, with the earth. When the machine is worked, the images dance in a very ludicrous manner. *Explain.* Pith balls may be substituted for the images, the resulting phenomena being known as "Volta's hail." The experiment may be simplified by electrifying the inner surface of a glass tumbler by rubbing it upon the knob of the prime conductor and placing the tumbler over some pith balls on the table.

FIG. 157.

Experiment 40.—Place a dozen pith balls or some bits of tissue paper on a table between two books about 2 inches (5 *cm.*) thick. Place a pane of glass upon the books as shown in Fig. 158. Rub the upper surface of the glass with the silk pad mentioned in § 302 (or a silk handkerchief) and notice the lively dance of the pith balls.

FIG. 158.

Experiment 41.—In the "electric chime," represented in Fig. 159, the outer bells are to be put into communication with the prime conductor; the central bell is in communication with the earth.

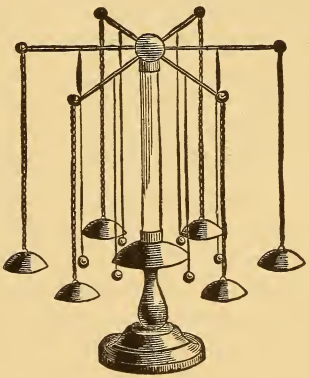


FIG. 159.

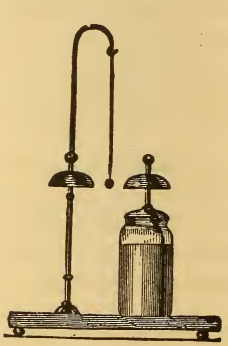


FIG. 160.

The clappers are suspended by silk threads. Work the machine slowly; the bells will begin to ring. *Explain.*

Experiment 42.—In the "Leyden jar and bells," shown in Fig. 160, the left-hand bell is in communication with the outer coat of the jar; the clapper is suspended by a silk thread. When the jar is charged and placed in position as represented, the bells begin to ring and continue to do so for a considerable time. *Explain.*

Experiment 43.—In the "electric swing," shown in Fig. 161, the boy is suspended by silk cords. One of the insulated knobs is in communication with the earth; the other with the prime conductor. When the machine is worked, the boy swings to and fro. *Explain.*

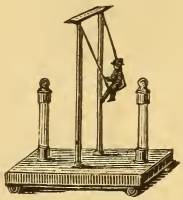


FIG. 161.

Experiment 44.—If a pupil hold a Leyden jar by the outer coat and, by a wire, connect the knob of the jar with the prime conductor, his knuckle will attract the balanced lath (Exp. 5) when the machine is worked. *Explain.*

Experiment 45.—Fasten a small paper kite by a linen thread to the prime conductor. When the machine is worked, the kite will float around the knob. *Explain.*

Experiment 46.—Fasten one end of a long, small, copper wire to the prime conductor. Near the other end of the wire, tie a silk cord and hang it from the ceiling or other support so that the end of the vertical part of the wire shall be at a convenient height. To this end of the wire attach a tassel about four or five inches long made of many strips of light tissue paper. Work the machine and the leaves will diverge. *Explain.* Extend toward it your clenched fist; the leaves seek the fist. *Explain.* Instead of your fist, hold a needle toward the tassel; it will be blown away. *Explain.* Hold the needle upright under the tassel. The strips will collapse. *Explain.*

Experiment 47.—Stand upon the insulating stool and place your left hand upon the prime conductor of the electric machine. Hold in your right hand a sewing-needle with the tip of the forefinger covering the end of the needle. Bring the right hand cautiously near the gold-leaf electroscope. Notice the divergence of the leaves. Now uncover the point of the needle and bring it near the electroscope. Notice the marked and immediate increase in the divergence of the leaves. *Explain.*

Experiment 48.—Place an "electric whirl" (which consists of a set of horizontal wire arms radiating from a pivot-supported centre,

the pointed ends being all bent in the same direction) upon the prime conductor. Work the machine and the arms will revolve. (Fig. 162.) *Explain.*

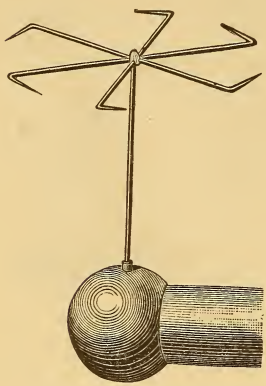


FIG. 162.

Experiment 49.—The "electric orrery," represented in Fig. 163, is a pretty modification of the "electric whirl." The short, balanced bar is provided with a pointed conductor to produce rotary motion upon its supporting pivot, which is one end of the long balanced bar. This longer bar is also provided with a pointed conductor and supported in turn upon a pivot, which may be attached to the prime conductor. When the machine is worked, the long bar revolves upon its fixed pivot; the short bar revolves upon its moving pivot.

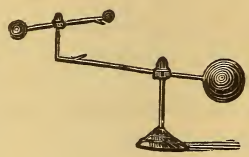


FIG. 163.

Experiment 50.—Half fill a wide, glass vessel with water. Within this, place a glass beaker and fill it to the same level with water. By a wire, connect the water in the outer vessel with the earth; in similar manner, connect the water in the beaker with the electric machine. Give the handle of the machine a *single* turn. Dipping one finger into the outer water and another into the inner water, a shock is felt. *Explain.*

Experiment 51.—Let a pupil stand upon an insulating stool (a board supported by four warm tumblers will answer) and place his left hand upon the prime conductor. Let him, with his right hand, clasp the left hand of another pupil not insulated, their hands being prevented from actual contact by an intervening sheet of india-rubber cloth. After the machine has been worked a moment, let the insulated pupil remove his left hand from the prime conductor and clasp the free hand of his companion. At this moment of clasping hands, a shock will be felt *Explain.*

Experiment 52.—Cover one knob of the discharger with gun cotton sprinkled with powdered rosin. When the Leyden jar is discharged with this discharger, the cotton and rosin are ignited.

Bring the covered knob of the discharger into contact with the knob of the jar with a quick motion.

Experiment 53.—The "electric bomb," represented in Fig. 164, may be made of ivory, heavy glass, or thoroughly seasoned wood. The ends of the two metal wires are rounded and placed a short distance apart. The bomb may be filled with gunpowder. One wire is connected by a chain with the outer coat of a charged Leyden jar. The other wire is to be connected with the inner coat by a *wet string* and the discharger. The spark between the ends of the two wires ignites the powder. Then try the experiment with air instead of powder.

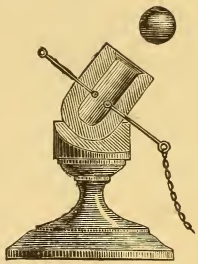


FIG. 164.

Experiment 54.—Fig. 165 illustrates a method of igniting an inflammable liquid, like ether or alcohol, by the electric spark. Through the bottom of a small glass vessel, *a*, passes a metal rod, having a knob at its upper extremity. The lower end of this rod may be brought into electrical connection with the outer coat of a Leyden jar. Enough ether or alcohol is poured into *a* just to cover the knob. When the jar is discharged in the way shown in the figure, the spark ignites the liquid. If alcohol is used, it may have to be warmed to render the experiment successful.

FIG. 165.

Experiment 55.—Let a pupil, standing on an insulating stool, become charged by holding one hand on the prime conductor when the

machine is in operation. If he then bring his knuckle to a metal burner from which a jet of gas is issuing, a spark will pass between the knuckle and the burner, igniting the gas. An Argand or Bunsen burner answers well for this experiment. The experiment may be modified by using, instead of the knuckle, an icicle held in the hand. The gas burner may be replaced by a pupil (not insulated) holding a spoonful of ether or of chloroform which readily gives off an easily combustible vapor.

Experiment 56.—The "universal discharger," shown in Fig. 166, consists of a glass table and two insulated metal rods. (See § 358 *a*.)

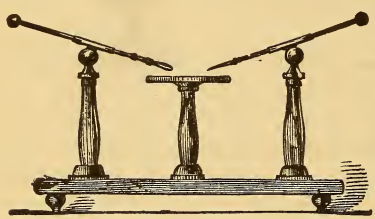


FIG. 166.

Balls, points and pincers are provided for use at the adjacent ends of the rods which are supported upon sliding and hinged joints, so that they may be easily placed in any desirable position. Cover the adjacent ends of the two rods with metal balls and place them upon the glass table, a small distance apart. Connect the balls by a very fine wire. One of the rods is to be connected by a wire or chain with the outer coats of a powerful battery; the other rod is to be connected, by the discharger, (Fig. 150) with the inner coats of the battery. The current thus passed along the fine wire may heat it to incandescence, melt or even vaporize it.

Experiment 57.—Prick a profile portrait of Franklin or some other design in a sheet of thin card board. Paste two pieces of tin-foil to the ends of the card and join them with a piece of gold leaf placed over the pricked design. Place a piece of white paper or silk on the other side of the card and have the whole tightly screwed up between two boards, leaving the edges of the tin-foil strips accessible. Discharge a Leyden battery through the gold leaf, thus volatizing it, sending the disintegrated particles through the holes in the card board and obtaining an impression of the portrait.

Experiment 58.—Fig. 167 represents "Volta's pistol," which consists of a metal vessel through one side of which passes an insulated metal rod with knobs at both ends. The knob at the inner end of this rod is near the opposite wall, so that a spark may easily be made to pass between the knob and the body of the pistol. The pistol being filled with a mixture of illuminating gas and common

air in equal volumes or with oxygen and hydrogen in the proportion of one volume of the former to two of the latter and, the mouth being closed by a cork, the passage of the spark brings about a chemical union of the mixed gases, a violent explosion ensues and the cork is thrown some distance. The spark may be produced by holding the pistol in the hand and bringing the outer knob near the prime conductor; or the pistol may be suspended from the prime conductor by a wire or chain and the pistol then touched with the hand. The pistol may also be fired by means of the electrophorus.

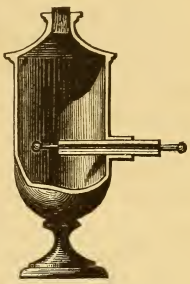


FIG. 167.

Experiment 59.—On the glass table of the universal discharger (Fig. 166), place a piece of wood and bring the *knobs* of the sliding rods against its ends so that the line joining the knobs shall be in the direction of the fibers of the wood. Through the apparatus thus arranged, discharge a powerful Leyden jar battery. The piece of wood will be torn in pieces.

Experiment 60.—Support a pane of glass upon a glass cylinder, in the axis of which is a pointed conductor that just touches the

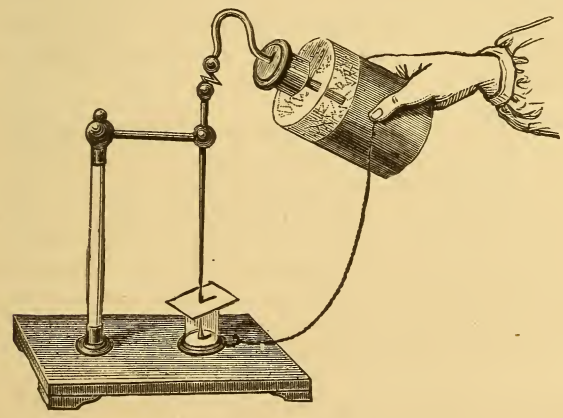


FIG. 168.

pane. On the upper side of the pane directly over this pointed conductor, place a drop of oil to prevent the spark from gliding over the surface of the glass instead of passing through. From an in-

sulated support, lower a second pointed conductor until it touches the pane at the oil. Through these two pointed conductors (Fig. 168), discharge a Leyden jar *or battery*. Unless the glass is *very thin*, a single jar will not be sufficient. If the experiment fails the first time, do not use the same piece of glass for the second trial. A plate of glass, 6 *cm.* thick, has been pierced by means of a powerful induction coil.

Experiment 61.—With corks, plug the ends of a glass tube filled with water. Through the corks, introduce copper wires until the ends in the water are within a quarter of an inch of each other. Through these wires, discharge a Leyden jar. The mechanical shock due to the repulsion of the electrified water molecules will often break the tube.

Experiment 62.—Charge a Leyden jar. In discharging it, hold a stiff card between the knob of the jar and the knob of the dis-

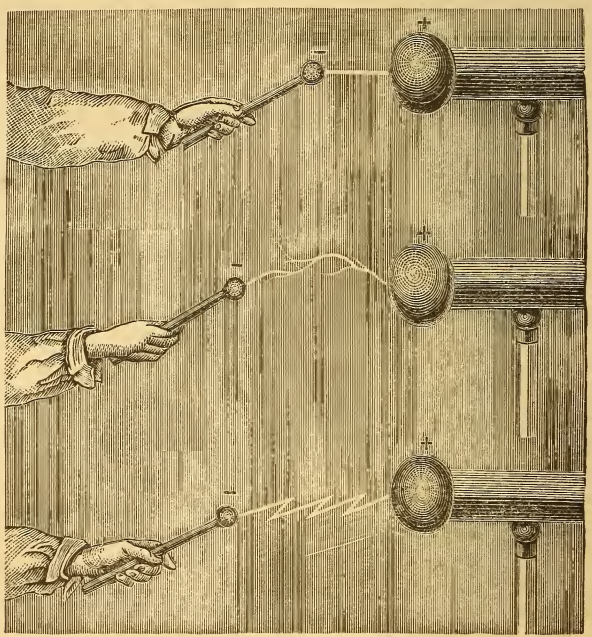


FIG. 169.

charger. A hole will be pierced through the card. By the side of this hole in the card, make another with a pin. Any one can tell

by examination of the pin-hole from which side of the card it was pierced; it is burred on only one side. Not so with the perforation made by this discharge; *it is burred on both sides.*

Experiment 63.—One of the inevitable experiments with an electric machine consists in "drawing sparks" from the conductor by the hand (Fig. 169). When the potential of the separated electricities becomes sufficient to overcome the resistance of the intervening air, they recombine with a sharp, explosive sound and brilliant flash of light. (§ 362.)

Experiment 64.—Divide a circle into black and white sectors, as shown in Fig. 170, and attach it to a whirling table (§ 74). Revolve it so rapidly that the colors blend and the disc appears a uniform gray. Darken the room and illuminate the rapidly revolving disc by the electric spark from a Leyden jar. The disc will appear at rest and each sector will appear separate from its neighbors. This shows that the duration of the electric spark is less than the persistence of vision.

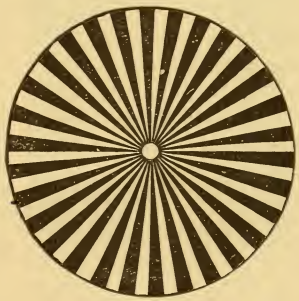


FIG. 170.

FIG. 171.

Experiment 65.—In a dark room, place a piece of loaf sugar in contact with the outside coat of a charged Leyden jar. Place one knob of the discharger upon the sugar and bring the other near the knob of the jar. When the jar is discharged thus through the sugar, the sugar will glow for some time.

Experiment 66.—The "luminous jar," represented in Fig. 171, is a modified Leyden jar. The outer coat consists chiefly of a layer of varnish sprinkled over with metallic powder. A strip of tin-foil at the bottom affords means of communication with the earth. A similar band at the upper edge of the outer coat is provided with an arm, as shown in the figure. The rod of the jar is curved so as to bring the knob near the projecting arm of the outer coat. The jar is suspended by the curved rod from the prime conductor

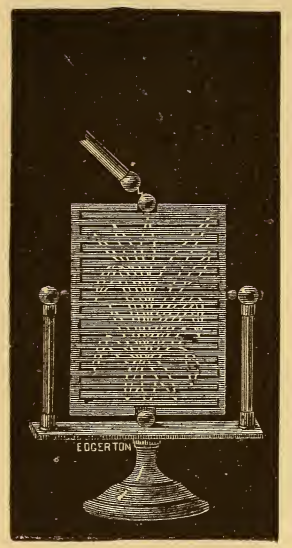


FIG. 172.

and its lower strip of tin-foil connected with the earth. When the machine is worked, sparks pass between the knob and the projecting arm. In a dark room, the metallic powder coat will be beautifully illuminated at the passage of each such spark.

Experiment 67.—The "luminous pane" is represented in Fig. 172. A continuous tin-foil strip is pasted back and forth upon the surface of a plate of glass. The upper end of this strip is connected with the prime conductor; the lower end with the earth. A series of breaks in this continuous conductor may be made by cutting it across with a sharp pen-knife. When the machine is worked, a small spark will appear at each break thus made. These breaks may be arranged so as to represent a flower, star, arch, word or other design. The sparks are really successive, but they seem to be simultaneous.

FIG. 173.

Experiment 68.—The "luminous globe" is represented in Fig. 173 and the "luminous tube" in Fig. 174. The first of these consists of a hollow glass globe, on the inner surface of which small discs of tin-foil are placed very near each other. The first disc is in connection with the prime conductor, and the last one with the ground. When the machine is

FIG. 174.

worked, bright sparks appear at each break between the discs. The construction and action of the luminous tube are similar. All of these luminous effects are best exhibited in the dark.

Experiment 69.—If two barometer tubes, united at the top, be filled with mercury and inverted over two cups of mercury, as shown in Fig. 175, a Torricellian vacuum will be formed at the bend. When the mercury of one cup is connected with the prime conductor and that of the other with the earth, the upper part of the tube (containing only mercuric and other vapors) is filled with light. The luminosity may be increased by raising the temperature and thus increasing the density of the aëriform conductor. (A true vacuum will not conduct electricity.) The apparatus may be put into the circuit of an induction coil instead of connecting it with the prime conductor and the earth.

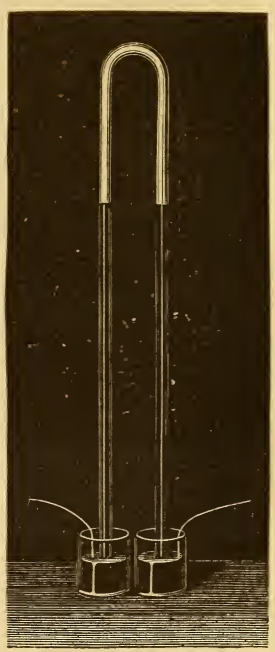


FIG. 175.

Experiment 70.—"Geissler's Tubes" are sealed glass tubes containing a highly rarefied vapor or gas. Platinum wires are sealed into the glass at each end, to conduct the electric current to the interior of the tube. The brilliancy and beauty of the light, the great variety of effects, color and fluorescence, are indescribable. They are made in great variety of form and size and filled with rarefied vapors and gases of many kinds. A few of the forms are represented in Fig.

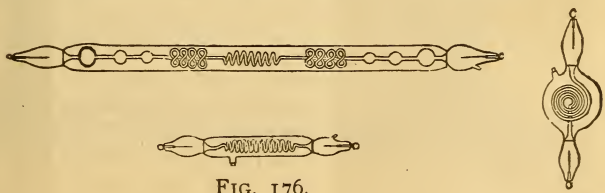


FIG. 176.

176. They may be used in the dark with an electric machine or an induction coil (§ 459).

Experiment 71.—In "Crookes's Tubes," devised in many forms by Prof. Crookes for his investigations of the phenomena of "radiant matter" (§ 59 *b*), the tension of the contained gas is reduced to about one millionth of an atmosphere, far below that of Geissler's tubes. Under the influence of the electric discharge, matter seems to be radiated from the negative pole in straight lines and in directions perpendicular to the radiating surface.

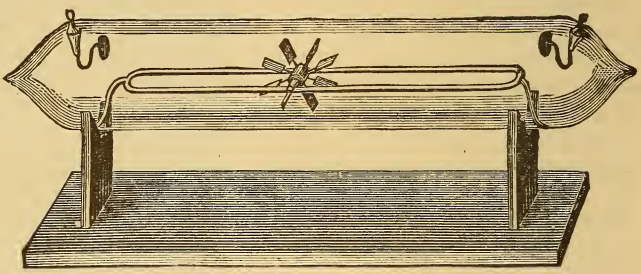


FIG. 177.

(*a*.) One of these tubes, used to show that "radiant matter" may exert mechanical action, is shown in Fig. 177. It consists of a highly exhausted glass tube containing a glass railway. The axle of a small wheel revolves on the rails, the spokes of the wheels carrying

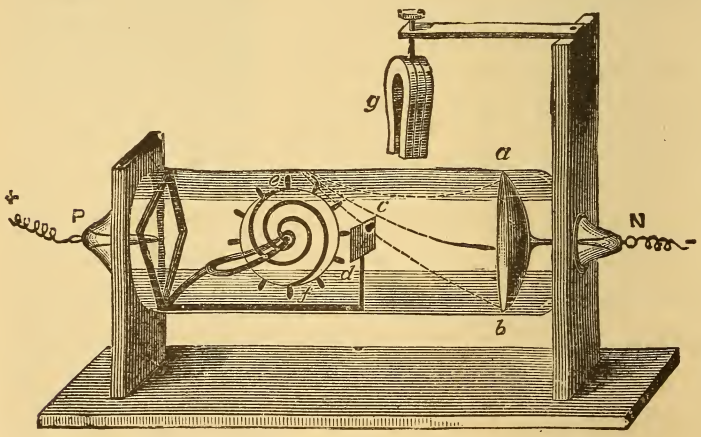


FIG. 178.

mica paddles. Pole pieces are fused in through the glass, as represented. Whichever pole is made negative, "radiant matter" darts

from it along the tube, strikes the upper paddles, causing the wheel to roll along the railway. By reversing the poles, the motion of the wheel may be stopped and reversed.

(*b*.) To show that "radiant matter" may be deflected from a straight line, he devised the tube shown in Fig. 178. The negative pole, *a b*, is in the form of a shallow cup. A mica screen, *c*, shields the mica paddle-wheel, *e f*. By holding one pole of the magnet, *g*, over the tube, the matter radiated from *a b* is deflected upward and the wheel caused to revolve like an overshot water-wheel. By holding the other pole of the magnet over the tube, the molecular stream is deflected downward and the wheel caused to revolve as an undershot water-wheel. (See Appendix C.)

372. Relation of Electricity to Energy.— The work necessarily performed in operating an electric machine is not all expended in overcoming inertia and friction. Much of it is employed in producing electric separation. It matters not whether this separation be the separation of two fluids or of something else. *Whatever be the nature of the realities separated, mechanical, kinetic energy is employed in the separation and converted into the potential variety* (§ 159).

An electrified pith ball or a charged Leyden jar is simply an electrostatical reservoir of potential energy. In the discharging of such a body, the passage of the current is accompanied by a loss of potential energy. What becomes of this energy? This leads us to look for effects due to it, to work done by it. Many illustrations of work thus done have been furnished in the experiments just described. In every case of electric attraction or repulsion, we have an evident reconversion of this potential energy into mechanical kinetic energy. We shall soon see that the sound, heat and light accompanying electric discharges are forms of energy due to the conversion of the potential energy of electric separation. We shall see other

effects, more or less powerful, when we come to study voltaic and other forms of current electricity.

Exercises.

1. (*a.*) If a gold-leaf electroscope be placed within a tin pail which is insulated and electrified, what will be the action of the electroscope? (*b.*) Explain.

2. (*a.*) Why may one obtain a stronger spark from a Leyden jar than from the machine by which it is charged? (*b.*) A Leyden jar standing upon a glass plate cannot be strongly charged. Why?

3. (*a.*) A globe that is polished will remain electrified longer than one that is not polished. Why? (*b.*) Can you devise an appendage to the outer coat of a Leyden jar, so that it may be charged when standing upon a plate of glass?

4. (*a.*) Describe the plate electric machine. (*b.*) Explain its action. (*c.*) Explain the action of the electrophorus.

5. (*a.*) A minute after the discharge of a Leyden jar, a second and feebler spark may generally be obtained. Explain. (*b.*) State two uses of lightning-rods.

6. (*a.*) Having a metal globe positively electrified, how could you with it negatively electrify a dozen globes of equal size without affecting the charge of the first? (*b.*) How could you charge positively one of the dozen without affecting the charge of the first?

7. Can you devise a plan by which a series of Leyden jars, placed upon a glass plate, may be simultaneously charged, the first positively, the second negatively, the third positively, the next negatively and so on?

8. How would you prove that there is no electrification within a closed conductor?

9. At what distance from a small sphere charged with 28 units of electricity must you place a second sphere charged with 56 units that one may repel the other with a force of 32 dynes? *Ans.* 7 *cm.*

10. If a number of Leyden jars be separately charged in the ordinary way and then connected in series, so that the outer coating of one is connected with the inner coating of the next, will the potential of the battery be changed and in what way?

11. Will the "striking distance" of a battery of Leyden jars in series be less or greater than the striking distance (*i.e.*, the greatest distance at which the discharge by spark will take place through air) of a battery of the same number of similar cells arranged abreast as shown in Fig. 152?

12. In what way may an electric charge be divided into three equal parts?

13. Suppose two similar conductors to be electrified, one with a + charge of 5 units and the other with a — charge of 3 units. They are made to touch each other. When they are separated, what will be the charge of each?

Ans. One unit of + electricity.

14. Why are telegraphic signals through a submerged cable retarded in transmission?

Recapitulation.—To be amplified by the pupil for review.

ELECTRICITY PRODUCED BY FRICTION.

- KINDS AND NAMES.
- ELECTROSTATIC LAWS.
- ELECTRICAL UNITS AND TESTS.
- ELECTROSCOPES.
- CONDUCTION.....
  - CONDUCTORS, NON-ELECTRICS.
  - INSULATORS, ELECTRICS.
- TENSION, POTENTIAL AND CAPACITY.
- ELECTRIFICATION.
  - BY CONTACT.
  - BY INDUCTION.
    - POLARIZATION.
    - ELECTROPHORUS.
    - ELECTRIC MACHINES.
    - SOURCE OF ENERGY.
- PROVISIONAL THEORY.
- DISTRIBUTION OF CHARGE.
  - ON SURFACE.
  - DENSITY.
- CONDENSERS.....
  - DIELECTRICS.
  - INDUCTIVE CAPACITY.
  - LEYDEN JAR.
  - LEYDEN BATTERY.
  - SUBMARINE CABLES.
- DISCHARGE.....
  - DISRUPTIVE.
  - CONVECTIVE.
  - CONDUCTIVE.
- ATMOSPHERIC E.
  - THUNDER STORMS.
    - LIGHTNING.
    - LIGHTNING-RODS.
  - AURORA BOREALIS.
- RELATION TO ENERGY.

SECTION III.

VOLTAIC AND THERMO-ELECTRICITY.

373. Chemical Action.—All chemical changes are accompanied by electric separation. The substances acted upon may be solid, liquid or aëriform, but the chemical action between liquids and metals gives results the most satisfactory. Electricity thus developed is called *voltaic or galvanic electricity.* Its energy is derived from the potential energy of chemical affinity (§ 7).

374. Current Electricity.—The principal classes of electric currents are as follows:

(1.) *Currents produced by chemical action, i. e., voltaic electricity.*

(2.) *Currents produced by heat, i. e., thermo-electricity.*

(3.) *Currents produced by other electric currents or by magnets, i. e., induced electricity.*

(*a.*) We have seen that, when a body having an electrical charge is properly connected with another of lower potential, there is a transfer of electricity from the former to the latter. This implies that there is an electric current. But this current is only momentary and of little importance in comparison with the currents that we are about to consider. Current electricity may differ from static electricity in quantity, electromotive force, *etc., but not in its nature.*

375. The Voltaic Current. — When a strip of copper and one of zinc are placed in dilute sulphuric acid

or in a battery solution like the one already used, the two strips being connected above the acid by a wire conductor, a current of electricity is produced. *The apparatus here described is called a voltaic or galvanic element or cell.*

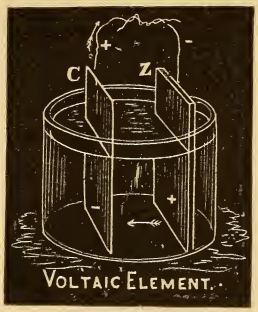


FIG. 179.

(*a*) For voltaic purposes, the sulphuric acid should be diluted by slowly *pouring the acid* into ten or twelve times its bulk of soft water. Do not pour the water into the acid.

376. Whence the Energy of Current?—The energy of the current is due to the potential energy of chemical affinity existing between the acid and the zinc. As the chemical affinity between coal and oxygen develops, in the furnace, a form of kinetic energy that we call heat, so the potential energy of chemical separation between the acid and the zinc develops, in the cell, the two varieties of kinetic energy, heat and electric current. The coal is consumed in the one case; the zinc, in the other.

377. Direction of the Current.—For this production of the electric current, it is necessary that the liquid have a greater action upon one plate than upon the other. The plate that is more vigorously acted upon by the liquid constitutes the generating or positive plate; the other, the collecting or negative plate. This relation of the plates determines the direction of the current. *In the liquid, the current is from the positive to the negative plate; in the wire, the current is from the positive to the negative electrode. In each*

case, the current passes from + to —. The direction of the current is indicated by arrows in Fig. 179.

When the wires from the two plates are in contact, it is said that the *circuit is closed;* when the plates are not thus in electric connection, it is said that the *circuit is broken.*

378. Electrodes.—It may help the memory to suppose that, in a voltaic cell, two currents, opposite in kind and direction, are simultaneously produced. It will be readily understood, by keeping in mind the direction of these two currents, that, if the circuit be broken, negative electricity will accumulate at the end of the wire attached to the positive plate and positive electricity at the end of the wire attached to the negative plate. *These ends of the wires are then called poles or electrodes. The negative pole is attached to the positive plate and vice versa. The plate or electrode from which the current flows is + ; that toward which the current flows is —.* Strips of platinum are often fastened to the ends of the wires; these platinum strips then constitute the electrodes.

379. Resistance.—Every electric circuit offers a resistance to the passage of the current. This resistance will, of course, depend largely upon the materials used for the circuit. (See Appendix K.)

(1.) *With a conducting wire of a given material, the resistance is proportional to the length.* If the resistance of a mile of telegraph wire be 13 ohms, the resistance of 50 miles of such wire will be (13 ohms $\times$ 50 =) 650 ohms.

(2.) *With a conducting wire of a given material,*

the resistance is inversely proportional to its sectional area, to the square of its diameter or to its weight per linear unit. If one conductor be twice the diameter of another made of the same length and material, the sectional area or the weight *per* foot or yard will be ($2^2=$) four times as great and the resistance of the first will be one-fourth as great as that of the second. If they be made of the same material and length, one weighing twice as much *per* foot as the latter, the resistance of the former will be half as great as that of the latter. (See Appendix I.)

(3.) *The resistance of a conducting wire of given length and thickness depends upon the material of which it is made, i. e., upon the specific resistance of the material.* (See Appendix K, [2].)

(4.) The resistance of a given conductor may vary with its temperature. (See Appendix K, [3].)

(*a.*) Conductivity and resistance are reciprocals, but it is more common to speak of the resistances of conductors than of their conductivities.

380. The Practical Unit of Resistance.— *The practical unit of resistance is called an ohm. A megohm is a million ohms. A microhm is one-millionth of an ohm.* The ohm is the resistance of a column of mercury one square millimeter in section and at the freezing temperature (0° C.). The exact length of this column is to be determined experimentally by an international commission. A recent determination of the value of the ohm (probably the best yet made) gives the mercury column a length of 106.3 *cm.* If the pupil will get, from some dealer in electrical supplies, 40 ft. of No. 24 insulated

copper wire (see Appendix I), he will have a very good standard ohm.

(*a.*) A galvanized iron (telegraph) wire, 4 millimeters in diameter and 100 meters long, or a pure copper wire, 1 millimeter in diameter and 48 meters long, has a resistance of about one ohm. An ohm equals 10^9 absolute electro-magnetic units (§ 452). (For the measurement of resistances, see Appendix M, [2 and 3].)

381. Examples.—(*a.*) If the resistance of 130 yd. of copper wire, $\frac{1}{16}$ inch in diameter, be one ohm, what is the resistance of 260 yd. of copper wire, $\frac{1}{32}$ inch in diameter? Since the diameter of the first wire is twice that of the second, the sectional area of the first will be four times that of the second. (Areas of circles are proportional to the squares of their diameters.) Therefore, the resistance of the same length (130 yds.) of the smaller wire will be four times that of the larger wire, or 4 ohms. But the second or smaller wire is twice as long. Therefore, its resistance will be twice ($\frac{260}{130}$) as great, or 8 ohms. *Ans.* 8 ohms.

(*b.*) What is the resistance of 20 yd. of platinum wire, 0.016 inch in diameter, if the resistance of 200 yd. of copper wire, 134 mils in diameter, is 0.34 ohm and the relative resistances of platinum and copper are as 11.3 : 1? (A *mil* is the one-thousandth of an inch. The term is frequently used in descriptions of wire.)

$$0.34 \text{ ohm} \times \frac{20}{200} \times \left(\frac{134}{16}\right)^2 \times \frac{11.3}{1} = 26.95 \text{ ohms.}$$

Ans. 26.95 ohms.

382. Electromotive Force.—Electromotive force (often written *E. M. F.* or simply *E.*) is the mysterious power that causes a transfer of electricity from one point to another. It is somewhat analogous to hydrostatic pressure. Wherever there is difference of potential, there is *E. M. F.* The terms are not synonymous, although, for convenience, *E. M. F.* is often expressed as difference of potential and *vice versa*. The *E. M. F.* of a voltaic cell depends upon the nature of the materials used and not upon the size of the plates or the distance between them.

The unit of electromotive force is called a volt. A microvolt is one-millionth of a volt.

A volt is a little less than the *E. M. F.* of a Daniell cell (§ 394), which measures 1.079 volts.

(*a.*) A volt equals 10^8 absolute electro-magnetic units (§ 452). (For the measurement of *E. M. F.* see Appendix M, [4].)

383. Internal Resistance. — We may imagine that the two plates of a voltaic cell are connected by a liquid prism. The greater the distance between the plates, the longer this prism and the greater its resistance. The larger the plates, the larger the prism and the less its resistance. (See Appendix M, [3].)

When the circuit is closed, hydrogen is set free by the decomposition of the liquid and rises from the surface of the negative plate. Gases are poor conductors. Hence, the hydrogen bubbles that often adhere to the negative plate increase the internal resistance of the cell by lessening the effective surface of the plate (§ 389). This tendency of the hydrogen to adhere to the plate is one of the practical difficulties to be overcome in working a voltaic cell or battery.

384. Fall of Potential.—The existence of a current is evidence of a difference of potential at any two consecutive points of the circuit. It may be well to compare the flow of electricity with the flow of water in horizontal pipes and difference of potential with difference of

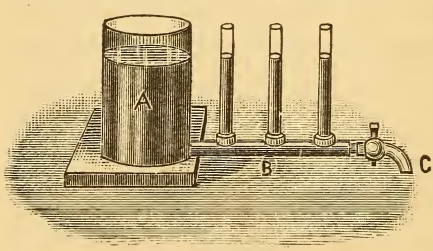


FIG. 180.

hydrostatic pressure. Let Fig. 180 represent a vessel filled with water. The tap at *C* is closed and the water stands at the same level in all of the vertical tubes (§ 234) showing that there is no difference of pressure and, consequently, no liquid flow. Similarly, when there is no difference of potential there is no electric flow. But when the tap at *C* is opened, as represented in Fig. 181, it is noticed that the level in the vertical tubes becomes lower as we pass from *A* toward *C*. The height of water in each vertical tube indicates the pressure at that part of the tube, *B*. This difference in hydrostatic pressure produces a flow of water. In much the same way, if the electric potential of a voltaic circuit be measured at different points, it will be found to decrease from the + pole to the − pole. If the circuit be a wire of uniform size and material, the resistance offered by it will be uniform and the potential will fall uniformly. If, however, the circuit be made to have a varying resistance in different parts, the potential will fall most rapidly along the parts of greatest resistance. For the whole or any part of the circuit, the fall of potential will be proportional to the resistance.

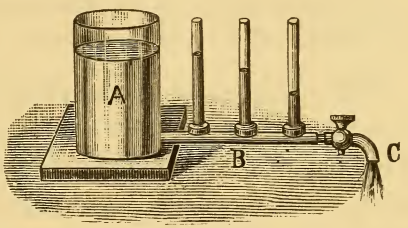


FIG. 181.

(*a.*) A number of hydraulic motors may be worked "in series" upon a given water pipe, the outflow of the first being the supply of the second. The work done in any motor may be determined from the quantity of water flowing through the pipe or motor per second and *the difference* between the supply pressure and the back pressure at the motor. There will be a fall of pressure between the two sides of the motor at work. The more work the motor has to do, the more

resistance it will offer to the flow of water and the greater the fall of pressure. Similarly, a number of telegraphic instruments or electric lamps may be placed in series upon an electric circuit. The work done in each instrument or lamp will depend upon the current strength and the difference of potential between the two terminals of the instrument or lamp. There will be a fall of a certain number of volts between the two terminals, depending upon the intervening resistance.

385. The Ampere.—The strength of current or its rate of flow (often called its intensity) will depend upon electromotive force and resistance, increasing with the former and decreasing with the latter. *The unit of current is called an ampere. One-thousandth of an ampere is called a milli-ampere.* At any given instant, the current is the same at every part of the circuit.

(*a.*) The telegraphic currents commonly used on main lines vary from 5 to 15 milli-amperes. The currents commonly used in electric arc lamps vary from 7 to 20 amperes.

(*b.*) The strength of a current may be measured by its heating effect (§ 471) or by the products of electrolysis, as in the case of the water voltameter (§ 410). But currents are generally measured by instruments like the galvanometer (§ 418), or by their electro-magnetic effects. An instrument so used is called an *ammeter* (abbreviated from ampere-meter). An ampere equals 0.1 or 10^{-1} of an absolute electro-magnetic unit (§ 452).

386. Ohm's Law.—*The strength of current varies directly as the E. M. F. and inversely as the resistance.* This resistance is the total resistance of the circuit, including the internal resistance of the cells or dynamo and the resistance of the external circuit.

$$\frac{Volts}{Ohms} = Amperes, \text{ or } C = \frac{E}{R}. \therefore E = C \times R;\ R = \frac{E}{C}.$$

Standards for strength of current have not yet been made.

(*a.*) Ohm's great service (A D., 1827) to electrical science consisted largely in the introduction of the accurate ideas, electromotive force, current strength and resistance. "Before his time, the quantitative circumstances of the electric current had been indicated in a very vague way by the use of the terms 'intensity' and 'quantity,' to which no accurately defined meaning was attached."

(*b.*) If we have a difference of potential that secures an E. M. F. of 18 volts, and if the total resistance of the circuit be 3 ohms, the strength of the current will be 6 amperes. $18 \div 3 = 6$. The analogy of flowing water will again help us. The rate at which the water is delivered will depend upon, not only the head or pressure (corresponding to E. M. F.), but also upon the resistance it meets with in flowing. If the pipe be small and crooked or if it be choked with sand or sawdust, the water will flow in a small stream even though the pressure be great.

Experiment 72.—Make four coils or spools of insulated wire as follows: (See Appendix I.)

No. 1, of 100 feet of No. 16 gauge, copper.
No. 2, of 100 " " 30 " "
No. 3, of 50 " " 30 " "
No. 4, of 50 " " 30 " german silver.

Place the wire of the first spool and a galvanometer (§ 418) in the circuit of one cell and note the number of degrees of deflection of the galvanometer needle. Put the second spool in place of the first. The smaller deflection shows that (other things being equal) the No. 16 wire transmits more current than the No. 30. Why? Then add the third spool to the circuit. The still smaller deflection shows that (other things being equal) a long wire transmits less current than a shorter one. Why? Remove the second spool from the circuit and note the deflection of the galvanometer. Put the fourth spool in place of the third. The diminished deflection shows that (other things being equal) a german silver wire transmits less current than a copper wire. Why? With any one of the spools in the circuit, compare the galvanometer deflections produced by a Bunsen cell and by a gravity cell and notice that the former gives the stronger current.

Note.—These experiments give *very crude results* but, such as they are, they fairly represent the measurements that prevailed until recently. More accurate measurements with numerical representations of the results are now demanded. The rapid advances of

electrical science within the last few decades have been very largely due to the adoption of definite units and accurate determinations. (See Appendix M.)

387. The Coulomb.—*The unit of quantity is called the coulomb. It is the quantity of electricity given by a one ampere current in one second.* A ten ampere current will give thirty coulombs in three seconds.

(*a.*) The word "quantity" was formerly used in the sense in which the word "intensity" was used in § 385, while the latter word was used as if it depended upon E. M. F. alone. But quantity of electricity, clearly, depends upon the strength of the current *and the time that the current flows.* A coulomb equals 0.1 or 10^{-1} of an absolute electro-magnetic unit of quantity (§ 452).

EXERCISES.

1. What length of No. 10 pure copper wire (B. & S.) will have a resistance of 1 ohm? (See Appendix I.) *Ans.* 961.54 ft.

2. A given battery has an E. M. F. of 12 volts. The internal resistance is 8 ohms. The resistance of the external circuit is 4 ohms. What is the strength of the current?

3. The 4 cells of a given battery are connected so that the total E. M. F. is 4 volts and the internal resistance is 20 ohms. The external circuit has a resistance of 20 ohms. What is the strength of the current? *Ans.* 0.1 ampere.

4. What length of copper wire 4 *mm.* in diameter will have the same resistance as 12 yd. of copper wire 1 *mm.* in diameter?

Ans. 192 yd.

5. The 4 cells of a given battery are connected so as to give an E. M. F. of 2 volts and to have a total internal resistance of 10 ohms. The external circuit is a stout copper wire with a resistance so small that it may be ignored. What is the current strength?

6. The same battery is used with a telegraphic sounder in the circuit. This instrument has a resistance of 5 ohms. What is the current strength? *Ans.* 133 milli-amperes.

7. The resistance of 47 ft. of copper wire, 22 mils in diameter being 1 ohm, find the resistance of 200 yd. of copper wire 134 mils in diameter *Ans.* 0.34 ohm.

☞ If you do not know what a mil is, consult the Index.

8. A battery has a current of 2 amperes flowing through a total resistance of 9 ohms. What is the E. M. F.?

9. The E. M. F. of a battery is 10 volts. The current is 1 ampere. The external resistance is 5 ohms. What is the internal resistance of the battery? *Ans.* 5 ohms.

10. The potential of a current falls 45 volts between the two terminals of an incandescence lamp. The current measures 1.25 amperes. What is the resistance of the lamp? *Ans.* 36 ohms.

☞ If you do not know what an incandescence lamp is, consult the Index.

388. Amalgamating the Zinc.—Ordinary commercial zinc is far from being pure. The chemically pure metal is expensive. When impure zinc is used, small closed circuits are formed between the particles of foreign matter and the particles of zinc. This *local action*, which takes place even when the circuit of the cell or battery is broken, rapidly destroys the zinc plate and contributes nothing to the general current. This waste, which would not occur if pure zinc were used, is prevented by frequently amalgamating the zinc. This is done by cleaning the plate in dilute acid and then rubbing it with mercury.

(*a.*) The method of amalgamating battery zincs practised by the author is as follows: In a glass vessel placed in hot water, dissolve 15 *cu. cm.* of mercury in a mixture of 170 *cu. cm.* of strong nitric acid and 625 *cu. cm.* of hydrochloric (muriatic) acid. When the mercury is dissolved, add 830 *cu. cm.* of hydrochloric acid. When the liquid has cooled, immerse the battery zinc in it for a few minutes, remove and rinse thoroughly with water. The liquid may be used over and over until the mercury is exhausted. The quantity here mentioned will suffice for 200 ordinary zincs or more. Keep the liquid, when not in use, in a glass-stoppered bottle.

389. Polarization.—It was stated in § 383 that the accumulation of hydrogen bubbles at the negative plate increases the internal resistance of the cell. But the hydrogen affects the current in another way. It acts like a positive plate (being almost as oxidizable as the zinc) and sets up an opposing electromotive force that tends to set a current in the opposite direction. *A cell or battery in this condition is said to be polarized.* Sometimes, as a result of polarization, the strength of the current falls off very greatly within a few minutes after closing the circuit. (See § 414.)

390. Varieties of Voltaic Cells.—All voltaic cells belong to one of two classes :

(1.) *Those using only one liquid.*

(2.) *Those using two liquids.*

All of the earlier batteries were composed of one-liquid cells.

Note.—When dilute sulphuric acid is mentioned in connection with cells and batteries, it may be understood that one volume of acid to ten or twelve volumes of water is meant.

391. Smee's Cell.—A Smee's cell is represented by Fig. 182. It consists of a platinized silver plate placed between two zinc plates hung in dilute sulphuric acid. The hydrogen bubbles accumulate at the points of the rough platinum surface and are more quickly carried up to the surface of the liquid and thus gotten rid of. The cell has an *available* electromotive force of about 0.47 volt.

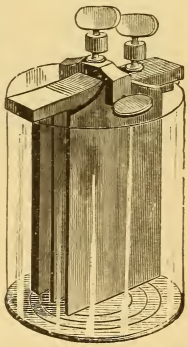


FIG. 182.

392. Potassium Di-chromate Cell.—The potassium di-chromate cell has a zinc plate hung between two carbon plates. A solution of potassium di-chromate (bi-chromate of potash) in dilute sulphuric acid is the liquid used. The hydrogen is given an opportunity for chemical union as fast as it is liberated. The E. M. F. of this cell is great to start with (from 1.8 to 2.3 volts), but it falls very quickly when the external resistance is small. It quickly recovers and may be used with advantage where powerful currents of short duration are often wanted. It is the only single liquid cell that is free from polarization.

(*a.*) The bottle form of this cell, represented in Fig. 183, is the most convenient for the laboratory or lecture table. By means of the sliding rod, the zinc plate may be raised out of the solution when not in use. Thus adjusted, the cell may remain for months without any action, if desired, and be ready at a moment's notice.

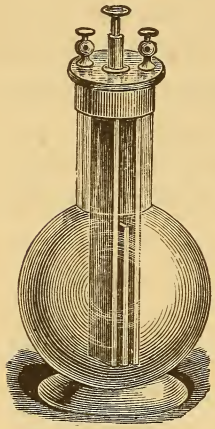


FIG. 183.

(*b.*) One of the best proportions for the solution is as follows: One gallon of water, one pound of potassium di-chromate and from a half pint to a pint of sulphuric acid, according to the energy of action desired. A small quantity of nitric acid added to the solution increases the constancy of the battery by oxidizing the nascent hydrogen and thus forming water.

(*c.*) The following recipe is good: Pour 167 *cu. cm.* of sulphuric acid into 500 *cu. cm.* of water and let the mixture cool. Dissolve 115 *g.* of potassium di-chromate in 335 *cu. cm.* of boiling water and pour, while hot, into the dilute acid. When cool, it is ready for use.

393. The Leclanche Cell.—This cell, shown in Fig. 184, contains a zinc plate or rod and a porous, earthenware cup containing the carbon plate. The space between the carbon plate and the cup is filled with fragments of carbon and powdered peroxide of manganese. This cup replaces the second metal plate. The liquid used is a solution of ammonium chloride (sal-ammoniac) in water. This cell is tolerably constant if it be not used to produce very strong currents, but its great merit is that *it is very permanent.* It will keep in good condition for months with very little attention, furnishing a current *for a short time* whenever wanted.

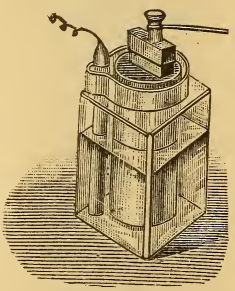


FIG. 184.

It is much used for working telephones, electric bells (Fig. 232) and clocks, railway signals, *etc.* The manganese oxide prevents polarization by destroying the hydrogen bubbles. If the cell be used continuously for some time, its power weakens owing to the accumulation of hydrogen, but if left to itself it gradually recovers as the hydrogen is oxidized. Sometimes the manganese oxide is applied to the face of the carbon and the porous cup dispensed with. This cell has an E. M. F. of about 1.5 volts. *It should be left on open circuit when not in use.*

394. Daniell's Cell.—This cell consists of a copper plate immersed in a saturated solution of copper sulphate (blue vitriol) and a zinc plate immersed in dilute sulphuric acid or a solution of zinc sulphate (white vitriol). The two liquids are separated; usually one liquid is contained in a porous cup placed in the other liquid. Crystals of copper sulphate are placed in the solution of copper sulphate to keep the latter saturated. Such a cell will furnish a nearly constant current, with an E. M. F. of 1.079 volts and keep in order for a long time. *It should be kept on closed circuit when not in use.* The hydrogen passes through the porous cell and acts upon the solution of copper sulphate. Copper, instead of hydrogen, is deposited upon the copper plate. Polarization is thus avoided. If an incrustation forms near the zinc plate, remove some of the solution of zinc sulphate and dilute what remains with water.

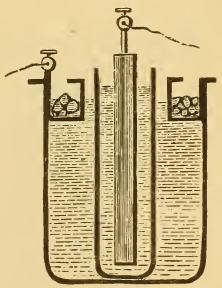


FIG. 185.

(*a.*) In Fig. 186, the copper plate is represented as a cleft cylinder within the porous cup, the crystals being piled up around it. It is common to interchange the plates, the zinc being in dilute sulphuric acid within the porous cup, and the copper plate in the saturated acid outside the porous cup. Sometimes the outer vessel itself is made of copper instead of glass and serves as the copper plate as is shown in Fig. 185.

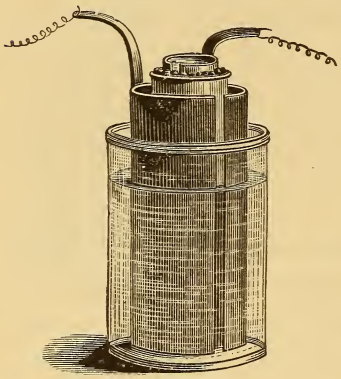


FIG. 186.

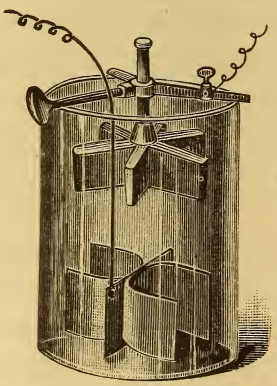


FIG. 187.

395 The Gravity Cell.—This is a modification of the Daniell's cell, no porous cup being used. The copper plate is placed at the bottom of the cell and the zinc plate near the top. Crystals of copper sulphate are piled upon the copper plate and covered with a saturated solution of copper sulphate. Water or, preferably, a weak solution of zinc sulphate rests upon the blue solution below and covers the zinc plate. The two solutions are of different specific gravities and remain clearly separated if the cell be kept on closed circuit when not in use. (Fig. 187.) This cell is very largely used in working telegraph lines. It is sometimes called the Callaud cell.

396. Grove's Cell.—The outer vessel of a Grove's cell contains dilute sulphuric acid. In this is placed a

hollow cylinder of zinc. Within the zinc cylinder is placed a porous cup containing strong nitric acid. The negative plate is a strip of platinum placed in the nitric acid. The hydrogen passes through the porous cup and reduces the nitric acid to nitrogen peroxide, which escapes as brownish-red fumes. These nitrogen fumes are disagreeable and injurious; it is well, therefore, to place the battery in a ventilating chamber or outside the experimenting room. The E. M. F. of the Grove cell, under favorable conditions, is nearly two volts, while its internal resistance is small, being about one-fifth that of a Daniell's cell. It is much used for working induction coils (consult the Index), for generating the electric light, *etc.* It is, however, troublesome to fit up and should have its liquids renewed every day that it is used. Fig. 189 represents a Grove's battery with cells *joined in series.*

397. Bunsen's Cell.— Bunsen's cell (Fig. 188) differs from Grove's in the use of carbon instead of expensive platinum for the negative plate, thus reducing the cost. The plates are made larger than for Grove's battery. Its E. M. F. is about the same as that of the Grove cell but its internal resistance is greater.

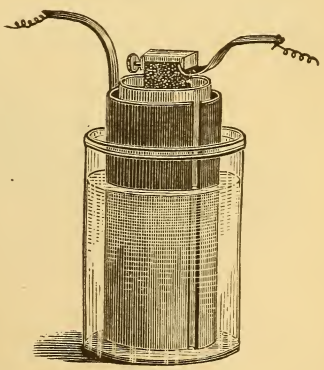


FIG. 188.

Fig. 190 represents a battery of Bunsen's cells *joined in multiple arc.*

Note.—There are scores of different kinds of cells in the market competing for favor. Those here described are among the ones most commonly used.

398. A Voltaic Battery.—*A number of similar voltaic elements connected in such a manner that the current has the same direction in all, constitutes a voltaic battery.* The usual method is to connect the positive plate of one element with the negative plate of the next, as shown in Fig. 189. When thus connected, they are said to be coupled "tandem" or "in series." Sometimes all of the positive plates are connected by a wire and all of the negative plates by another wire. The cells are then said to be joined "parallel," "abreast" or "in multiple arc." (See Fig. 190.)

(*a.*) When two or more cells are joined together, the points of contact should be as large as is convenient and kept perfectly clean. The connecting wire should be of good size and, for the sake of pliability, a part of it may well be given a spiral form by winding it upon a pencil or other small rod.

399. Batteries of High Internal Resistance.—Each kind of galvanic cell has an internal resist-

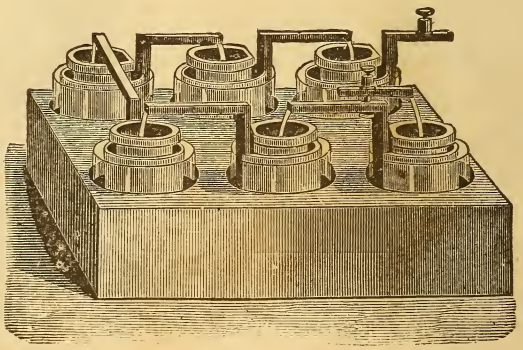


FIG. 189.

ance, as explained in § 383. A battery of cells joined in series is called a "battery of high internal resistance." (Fig. 189). This method of joining the cells increases

the length of the liquid conductor through which the current passes.

(*a.*) In a battery of cells joined in series, the E. M. F. and the internal resistance are those of a single cell multiplied by the number of cells. For a circuit of great external resistance, a battery of high internal resistance is needed.

400. Batteries of Low Internal Resistance.—A battery of cells joined parallel is called a "battery of low internal resistance." (Fig. 190.) This method of joining the cells does not increase the length of the liquid conductor traversed by the current but is equivalent to increasing its diameter or sectional area.

(*a.*) In a battery of cells joined parallel, the E. M. F. is that of a single cell, but the internal resistance is that of a single cell divided by the number of cells. For a circuit of small external resistance, large cells, or several cells joined parallel, are preferable.

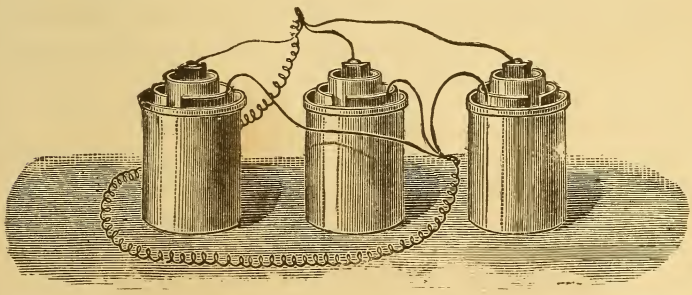


FIG. 190.

(*b.*) A battery of high internal resistance was formerly called an *intensity* battery, while a battery of low internal resistance was called a *quantity* battery.

401. Requisites of a Good Battery.—The following conditions should be met by a battery:

(1.) Its electromotive force should be high and constant.

(2.) Its internal resistance should be small.

(3.) It should give a constant current and, therefore, must be free from polarization; it should not be liable to rapid exhaustion, requiring frequent renewal of the acid.

(4.) It should be perfectly quiescent when the circuit is open.

(5.) It should be cheap and of durable materials.

(6.) It should be easily manageable and, if possible, should not emit corrosive fumes.

As no single battery fulfills all these conditions, some batteries are better for one purpose and some for another. Thus, for telegraphing through a long line of wire a considerable internal resistance in the battery is no great disadvantage; while, for producing an electric light, much internal resistance is absolutely fatal.

402. The Best Arrangement of Cells.—The best method of coupling cells in any given case depends on the work to be done by the battery. *The maximum effect is attained when the resistance of the external circuit is made equal to the internal resistance of the battery.*

(*a.*) For example, suppose that in a given battery of eight cells:

(1.) Each cell has an E. M. F. of two volts.

(2.) Each cell has the very high internal resistance of eight ohms.

(3.) The battery is to work through a wire that has a resistance of sixteen ohms.

(*b.*) First, couple the cells parallel. The E. M. F. of the battery is that of a single cell, 2 volts. The internal resistance is 8 ohms $\div$ 8 = 1 ohm. Adding the external resistance, we have a total resistance of 17 ohms. (See § 386.)

$$C = \frac{E}{R} = \frac{2}{1 + 16} = 0.1176+.$$

This arrangement gives a current of 0.1176+ amperes.

(*c.*) Next, couple the cells in series. The E. M. F. of the battery is 8 times 2 volts, or 16 volts. The internal resistance is 8 times 8 ohms or 64 ohms. Adding the external resistance, we have a total resistance of 80 ohms.

$$C = \frac{E}{R} = \frac{16}{64 + 16} = 0.2.$$

This arrangement gives a current of 0.2 amperes.

(*d.*) Finally, join the cells in two rows (each row being a series of four cells) and join the rows parallel. The E. M. F. of the battery will be 4 times 2 volts or 8 volts. The internal resistance will be 4 times 8 ohms or 32 ohms for each row, but only half that, or 16 ohms, for the whole battery. Adding the external resistance, we have a total resistance of 32 ohms.

$$C = \frac{E}{R} = \frac{8}{16 + 16} = 0.25.$$

This arrangement, in which the internal and the external resistances are equal, gives a current of 0.25 amperes, the greatest possible under the given conditions.

(*e.*) A similar application of Ohm's law shows that *when the external resistance is large, there is little gain from joining cells parallel, and that when the external resistance is very small, there is little gain in joining cells in series.*

Exercises.

1. Given ten cells, each with an electromotive force of 1 volt and an internal resistance of 5 ohms. What is the current (in amperes) of a single cell, the external resistance being 0.001 ohm?

Ans. 0.19996+ amperes.

2. The ten cells above mentioned are joined abreast. The external resistance is 0.001 ohm. What is the current of the battery?

Ans. 1.996+ amperes.

3. The ten cells above mentioned are joined tandem, the external resistance remaining the same. What is the current of the battery?

Ans. 0.19999+ amperes.

4. What is the current given by one of the above mentioned cells when the external circuit has a resistance of 1000 ohms?

Ans. 0.00099502 amperes.

5. When the ten cells are joined abreast with an external resistance of 1000 ohms, what is the current of the battery?

Ans. 0.0009995 amperes.

6. When the ten cells are joined in series with an external resistance of 1000 ohms, what is the current of the battery?

Ans. 0.00992 amperes.

Note.—Compare the results in Exercises 1, 2 and 3, where we have a small external resistance. Then compare the results in Exercises 4, 5 and 6, where we have a high external resistance.

7. Why are cells arranged tandem for use on a long telegraphic line?

8. What is the resistance of 2 miles of No. 6 electric light wire (copper of ordinary commercial quality)? (See Appendix I.)

Ans. 4.54 ohms.

9. A Brush dynamo, No. 8, will operate 65 arc lamps on a short circuit. Each lamp has a resistance of about 4.52 ohms. If the lamps be put on a 10 mile circuit of No. 6 copper wire, how many lamps should be "cut out" of the circuit, the dynamo running at the same speed and the current strength remaining the same?

Ans. 5 lamps.

10. Show, by a diagram, how a battery of three cells should be arranged when the internal resistance is the principal one to be overcome.

11. What is the resistance of a mile of ordinary No. 6 iron telegraph wire? (See Appendix K, [2].) *Ans.* 12.9 ohms.

12. Show that the conductivity of water is increased more than 50 times by adding half its volume of sulphuric acid. (See Appendix K, [2].)

13. How much is the conductivity of water increased by adding $\frac{1}{11}$ its volume of sulphuric acid? *Ans.* About 22 times.

403. Long and Short Coil Instruments.—A "long coil" galvanometer, or a "long coil" electro-magnet, or an instrument of any kind in which the conductor is a long, thin wire of high resistance, should not be employed on circuits the other resistances of which are small. Conversely, on circuits of great length, or where there is a high resistance, "short coil" instruments are of little service for, though they add little to the resistances, their few turns of wire are not enough with the small currents that circulate in high-resistance circuits; "long coil" instruments are here appropriate, as they multiply the effects of the currents by their many turns. Their resistance, though perhaps large, is not a serious addition to the existing resistances of the circuit.

404. Divided Circuits and Shunts.—The case of several wires forming a multiple arc often occurs in practice. In such cases, *the current flowing in each branch is inversely proportional to the resistance of that branch.* Either of two such branches is called a shunt. Evidently, the joint resistance of all the branches is less than the resistance of any one of them.

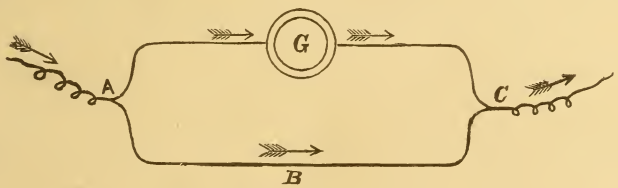


FIG. 191.

(*a.*) A current flowing along a conductor divides at *A*, part going through a galvanometer or electro-magnet at *G* and the rest going through the branch, *B*. The currents unite at *C*. If the conductor, *AGC*, has a resistance of 99 ohms and the conductor, *ABC*, has a

resistance of 1 ohm, 1 per cent. of the total current will go through G and 99 per cent. will go by way of B.

(*b*.) If we have two wires, the separate resistances of which are respectively 28 ohms and 24 ohms, placed abreast in a circuit, find their joint resistance. The joint conductivity will be the sum of the separate conductivities and conductivity is the reciprocal of resistance. Call the joint resistance R.

$$\frac{1}{R} = \frac{1}{28} + \frac{1}{24} = \frac{24}{672} + \frac{28}{672} = \frac{52}{672}. \quad \therefore R = \frac{672}{52} = 12.92.$$

The joint resistance will be 12.92 ohms.

(*c*.) The joint resistance of the two branches of a divided conductor is equal to the product of the separate resistances divided by their sum. If there are more than two branches, the method employed above may be used.

(*d*.) It is often necessary to use a sensitive galvanometer or other instrument with a current so strong that the current would give indications too large for accurate measurement or even ruin the instrument. Under such circumstances, the greater part of the current may be shunted around the galvanometer. The resistance of the shunt having a known ratio to that of the galvanometer and its branch, the total current strength may be computed from the strength of the current flowing through the instrument. Shunt circuits may be found in almost all arc lamps.

405. Mechanical Effects of the Electric Current.—The piercing of the glass walls of an overcharged Leyden jar affords a good, though expensive, illustration of the mechanical effects of electricity. Trees and telegraph poles shattered by lightning are not unfamiliar. But, by far, more important for our consideration are the mechanical effects produced by voltaic or dynamic electricity and, especially, *the numerical relation between the electricity used and the work done.* This subject will be considered in Section VI. of this chapter.

Experiment 73.—Through a long, thin platinum wire, send a current that will heat it to dull redness. Apply a piece of ice to the

wire and notice that the rest of the wire glows more brightly than it did before. Then heat a part of the wire with the flame of a spirit lamp and notice that the rest of the wire glows less brightly than before. In the first case, the current is strengthened by the increased conductivity of the cooled part; in the second case, the current is decreased by the increased resistance of the part heated by the lamp.

Experiment 74.—When two curved metal surfaces rest upon each other, a current passing from one to the other encounters considerable resistance at the small area of contact. The heat consequently developed causes the parts in the neighborhood to expand very quickly when the contact is made. This often gives rise to rapid vibratory movements in the conductors. *Gore's railway* consists of two concentric copper hoops, whose edges are worked very truly into a horizontal plane. A light copper ball is placed on the rails thus formed. One rail is connected with the + pole of a battery of two or three Grove cells and the other rail with the − pole. The ball is then set rolling around the track. If the ball be true and the track well leveled, the energy supplied by the swelling (expansion) at the continually changing point of contact is sufficient to keep up the motion. The ball will roll round and round, giving a crackling sound as it goes.

Experiment 75.—From the poles of a potassium di-chromate battery, lead two stout copper wires and connect their free ends by two or three inches of *very fine iron or platinum wire.* Coil the iron wire around a lead pencil and thrust a small quantity of gun-cotton into the loop thus formed. Plunge the zinc plate of the battery into the liquid and the iron wire will be heated enough to explode the gun-cotton; it may be heated to redness or even to fusion.

406. Thermal Effects of the Electric Current.—Whenever an electric current flows through a conductor, *part of the electric energy is changed into heat energy. The amount of electricity thus changed into heat will depend upon the amount of resistance offered by the conductor.* In the last experiment, the stout copper wires were good conductors, offered but little resistance and converted but little of the

electrical energy into heat energy. The change of material from copper to iron increased that resistance. This increased resistance was again increased by reducing the size of the conductor. For this double reason, the *fine wire* offered so much resistance that a considerable of the current energy was transformed into heat. *Resistance in an electric circuit always produces heat at the expense of the electric current.* Thus, electricity is often used in firing mines in military operations and in blasting. All known metals have been melted in this way, while carbon rods have been heated by a battery of 600 Bunsen's elements until they softened enough for welding. By means of a Leyden jar battery and a universal discharger, remarkable thermal effects may be obtained. Houses are sometimes set on fire by lightning. The numerical relations between electricity and heat are considered in Section VI. of this chapter.

407. Luminous Effects of the Electric Current.—The electric spark, the glow seen when electricity escapes from a pointed conductor in the dark and the various forms of lightning are some of the now familiar luminous effects of electricity. Whenever an electric circuit is closed or broken, there is a spark at the point of contact, due to the heating of a part of the conductor to incandescence. We have seen luminous effects produced by winding the wire from one plate of a voltaic cell round one end of a file and drawing the other electrode along the side of the file, thus rapidly closing and breaking the circuit. If the iron wire used in the last experiment was heated sufficiently, it also gave a luminous effect

and illustrated the fundamental principle of the incandescence electric lamp (§ 466).

(*a.*) The most important luminous effects of electricity will be considered in connection with dynamo-electric machines (§ 465). It will be noticed that all of these are secondary thermal effects.

408. Galvani's Experiment.—In 1786, Galvani, a physician of Bologna, noticed convulsive kicks in a

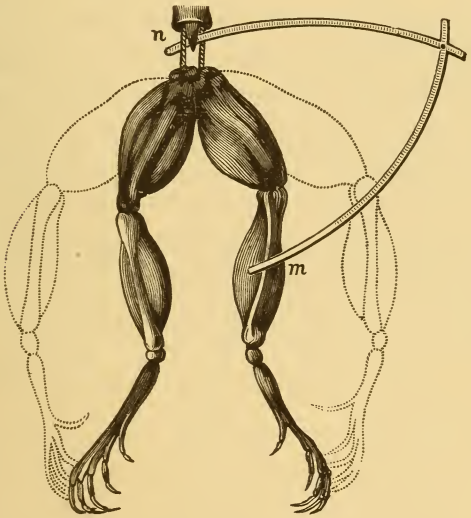


FIG. 192.

frog's legs when acted upon by an electric current. A frog was killed and the hind limbs cut away and skinned, the crural nerves and their attachments to the lumbar vertebræ remaining. Two dissimilar metals were held in contact and their free ends brought into contact with nerve and muscle respectively, as shown in Fig. 192. Convulsive muscular contractions brought the legs into a position similar to

that represented by the dotted lines in the figure. A frog's legs thus prepared make a very sensitive galvanoscope. It is said that they show even the very feeble induction currents of the telephone, though the best galvanometers barely detect them.

409. Physiological Effects of the Electric Current.—An electric current may produce muscular convulsions in a recently killed animal. Experiments with the Leyden jar and the induction coil show that similar effects may be produced upon the living animal. The "electric shock," which is physiological in its nature, is familiar to most persons. The sensation thus produced cannot be described, forgotten or produced by any other agency.

Electricity is largely used as an agent for the cure of disease; experiments of this kind may do injury and would better be left to the educated physician. The discharge of a large battery may be fatal and a number of persons have lost their lives within the last few years by coming, accidentally or otherwise, into the circuit of a dynamo-electric machine. Interrupted and alternating currents are more serious in their physiological effects than continuous currents.

(*a.*) If the members of a class form a chain by joining hands, the first member holding a feebly-charged Leyden jar by its outer coat and the last member touching the knob, a simultaneous shock will be felt by each person in the chain. A similar experiment may be made with a Ruhmkorff coil. A single Leyden jar has been discharged through a regiment of 1500 men, each soldier receiving a shock. Dr. Priestley killed a rat with a battery of seven feet of coated surface, and a cat with a battery of forty feet of coated surface.

Experiment 76.—Into a bent tube (known to dealers in chemical glassware as a U tube), put a solution of any neutral salt, *e. g.*, sodium sulphate. Color the contents of the tube with the solution from purple cabbage. In the arms of the tube, place the platinum electrodes of a battery, as shown in Fig. 193. Close the circuit and presently the liquid at the + electrode will be colored red and that at the — electrode, green. If, instead of coloring the solution, a strip of blue litmus paper be hung near the + electrode it will be reddened, while a strip of reddened litmus paper hung near the — electrode will be colored blue. *These changes of color are chemical tests;* the appearance of the green or blue denotes the presence of an alkali (caustic soda in this case), while the appearance of the red denotes the presence of an acid.

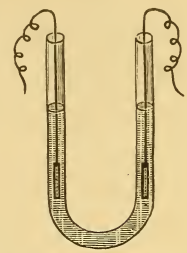


FIG. 193.

Experiment 77.—Melt some tin and pour the melted metal slowly into water. Dissolve some of this granulated tin in hot hydrochloric acid and add a little water. Into this bath of a dilute solution of tin chloride, introduce two platinum electrodes from a battery of a few cells. A remarkable growth of tin crystals will shoot out from the — electrode and spread towards the +, bearing a strong resemblance to vegetable growth. Hence, it is called the "tin tree." Repeat the experiment with solutions of lead acetate ("sugar of lead") and of silver nitrate.

410. Chemical Effects of the Electric Current.—The electric spark may be made to produce chemical combination or chemical decomposition. Ammonia (NH_3), or carbon-dioxide (CO_2), may be decomposed by passing a series of sparks through it. A mixture of oxygen and hydrogen may be caused to enter into chemical union by the electric spark, the product of the union being water. (See *Chemistry*, Exp. 53.) Many chemical compounds may be decomposed by passing the current through them. The compound must be in the liquid condition, either by solution or by fusion. Substances that are thus decomposed are called *electrolytes;* the process is called *elec-*

trolysis; the compound is said to be *electrolyzed.* The electrolysis of acidulated water is easily accomplished with a current from three or four Grove's or Bunsen's cells. The water is decomposed into oxygen and hydrogen. The apparatus, shown in Fig. 194, may be called a *water-voltameter.*

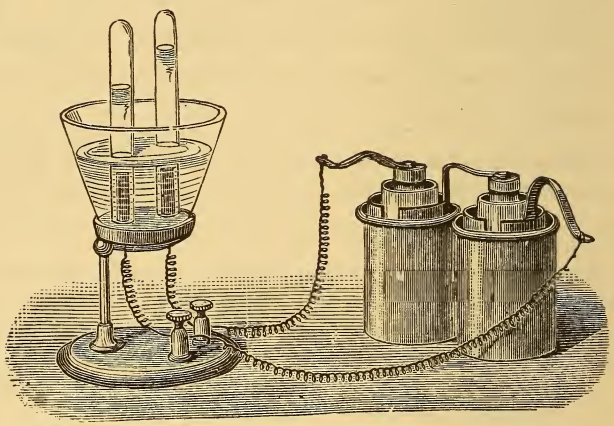


FIG. 194.

(*a.*) The apparatus consists of a vessel containing water (to which a little acid has been added to increase its conductivity) in which are immersed two platinum strips that constitute the two electrodes of a battery. When the circuit is closed, bubbles of oxygen escape from the positive electrode and bubbles of hydrogen from the negative. The gases may be collected separately by inverting, over the electrodes, tubes filled with water, as shown in the figure. The volume of hydrogen thus collected will be about twice as great as that of the oxygen.

(*b.*) A water-voltameter may be made by cutting off the bottom of a wide-mouthed glass bottle (*Chemistry, App.* 4, *h.*) and passing two insulated wires, varnished and terminating in platinum strips, through a cork that closes the mouth of the inverted bottle. Two test tubes will complete the instrument. When a sufficient quantity of the gases has been collected, they may be tested; the hydrogen, by bringing a lighted match to the mouth of the test tube, whereupon the hydrogen will burn; the oxygen, by thrusting a splinter

with a glowing spark into the test tube, whereupon the splinter will kindle into a flame.

(*c.*) Each coulomb of electricity liberates 0.1176 *cu. cm.* of hydrogen and 0.0588 *cu. cm.* of oxygen, or a total of 0.1764 *cu. cm.* of the mixed gases. The electrolysis of 9 *g.* of water requires 95,050 coulombs.

411. Ions.—The products of electrolysis, like the oxygen and hydrogen, are called *ions;* the one that goes to the + electrode (or anode) is called the *anion;* the one that goes to the — electrode (kathode or cathode) is called the *kathion* or *cathion.*

(*a.*) The amount of chemical action *in a cell* is proportional to the strength of current while it passes. One coulomb of electricity, in passing through a cell, liberates 0.0000105 gram of hydrogen and dissolves 0.00034125 gram of zinc.

(*b.*) One coulomb will cause the deposition of 0.0003307 gram of copper. To deposit 1 gram of copper requires 3024 coulombs. This principle has been used in the Edison meter for electric lighting purposes, a certain proportion of the current being shunted through a "copper voltameter" or bath of copper sulphate solution, as described in the next experiment.

Experiment 78.—From the + pole of a voltaic battery or dynamo-electric machine, suspend a plate of copper; from the — pole,

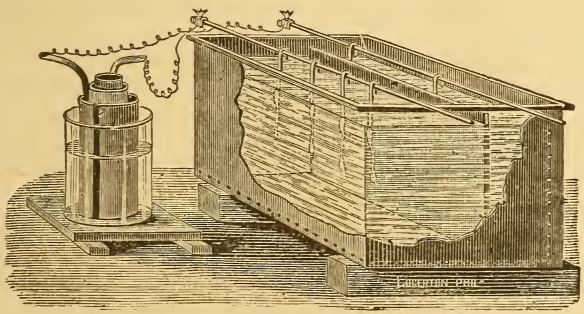


FIG. 195.

suspend a silver coin. Place the copper and silver electrodes in a strong solution of copper sulphate (blue vitriol). When the circuit

is closed, the salt of copper is electrolyzed, the copper from the salt being deposited upon the silver coin and the sulphuric acid going to the copper or + electrode. The silver is thus electro-plated with copper. (Fig. 195.)

412. Electro-Metallurgy. — The many applications of this process of depositing a metallic coat on a body prepared for its reception, constitute the important art of electro-metallurgy. If, with the apparatus used in the last experiment, a solution of some silver salt be used instead of the copper sulphate solution and the direction of the current be reversed, silver will be deposited upon the copper plate, which will thus be *silver-plated.* If the positive electrode be a plate of gold and the bath a solution of some salt of gold (cyanide of gold dissolved in a solution of cyanide of potassium), gold will be deposited upon the copper of the negative electrode, which will be thus *electro-gilded.* In *electrotyping*, impressions of type or engravings are taken in wax, or any other plastic material that is impervious to water. A conducting surface is given to such a mould by brushing finely powdered graphite over it; it is then placed in a solution of sulphate of copper facing a copper plate. The mould is then connected with the — pole of a dynamo or a voltaic battery and the copper, with the + pole; when the current passes through the bath, copper will be deposited upon the mould. When the copper film is thick enough (say as thick as an ordinary visiting card), it is removed from the mould and strengthened by filling up its back with melted type-metal. The copper film and the type-metal are made to adhere by means of an amalgam of equal parts of tin and lead. The copper-faced plate thus produced is an exact

reproduction of the type and engravings from which the mould was made.

(*a.*) In all these cases, the metal is carried in the direction of the current and deposited upon the negative electrode. In electro-plating and gilding, the technicalities of the art refer chiefly to the means of making the deposit firmly adherent. In electrotyping, they refer chiefly to the preparation of the mould or matrix.

413. Electro-Chemical Series.—The facts just considered suggest a division of substances into two classes, electro-positive and electro-negative. *The ion that goes to the negative electrode is called electro-positive; that which goes to the positive electrode is called electro-negative.*

(*a.*) Kathions are called electro-*positive* because they seem to be attracted to the *negative* pole of the battery (kathode), the idea being that of attraction between opposite electricities. Hydrogen and the metals are kathions or electro-positive. They seem to move with the current, going as far as possible and being deposited where the current leaves the "bath" or electrolytic cell. Similarly, anions are said to be electro-negative.

414. The E. M. F. of Polarization.—The products of electrolysis have a tendency to reunite by virtue of their chemical affinity. (*Chemistry*, § 8.) For example, the electrolysis of zinc sulphate gives zinc and sulphuric acid. But we now well know that the chemical action of these two substances has an electro-motive force of its own. This E. M. F. of the ions acts in opposition to that of the electrolyzing current. In some cases, it rises higher than the E. M. F. of the original current *and reverses the direction of the current.* The oxygen and hydrogen, yielded by the electrolysis of water, tend to reunite and set up an opposing E. M. F. of about 1.45 volts.

Thus we see that it requires a battery or cell with an E. M. F. of more than 1.45 volts to decompose water. *This electro-motive force of the ions is called the E. M. F. of Polarization.* It may be observed by putting a galvanometer in the place of the battery of the water-voltameter (Fig. 194). The polarization in a voltaic cell acts in the same way.

(*a.*) There is no opposing E. M. F. of polarization when the kathion and the anode are of the same metal. For example, the feeblest current will deposit copper from a solution of copper sulphate, *when the anode is a copper plate.*

Experiment 79.—Suspend two strips of bright sheet lead facing each other in dilute sulphuric acid. Pass a current through these plates by connecting them with a battery of 4 or 5 cells in series. A dark peroxide of lead will form on one of the bright plates. Then remove the battery and, in its place, put a short coil galvanometer or electro-magnet. It will be found that the lead-plate cell is supplying a current, the direction of which is the reverse of the charging battery previously used.

415. Secondary Batteries.—When a voltameter or an electro-plating bath is supplying a current of electricity, as mentioned in the last paragraph, it constitutes a secondary battery. As the ions do not reunite when the circuit is open, the energy of the decomposing current may be stored up as energy of chemical affinity. *When a current is again wanted, the circuit may be closed and the energy of chemical affinity at once appears as energy of electric current. Secondary batteries are, consequently, often called storage batteries.*

(*a.*) The Faure battery consists of two plates of sheet lead coated with red lead (lead sesqui-oxide, Pb_3O_4). These plates are sepa-

rated by a layer of paper or cloth, rolled up in a loose coil like a roll of carpet and immersed in dilute sulphuric acid.

(*b.*) When a current from a dynamo-electric machine or a voltaic battery is sent through such a cell, chemical action is produced. Oxygen acts on the coating of the anode plate and converts it into a higher oxide of lead (the peroxide, PbO_2). Hydrogen acts upon the coating of the kathode plate and reduces it to metallic lead in a spongy condition. When these changes have gone as far as possible, the battery is said to be "charged." The charged plates will remain in this condition for days *if the circuit be left open.*

(*c.*) By closing the circuit, the plates will, at any time, furnish a current until they are changed to their original chemical condition. As the lead plates and the acid are not rapidly destroyed, the battery may be charged and discharged many times.

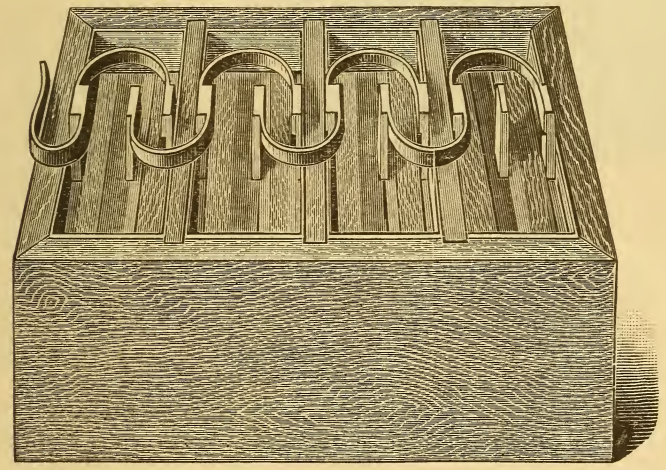


FIG. 196.

(*d.*) Many serious defects in the Faure battery have been obviated in the Brush battery (Fig. 196). These batteries are composed of a number of cells containing cast lead plates of a peculiar construction, electro-chemically prepared and immersed in dilute sulphuric acid. These cells may be connected together, tandem or abreast, so as to produce any desired result. A large number of these batteries may be placed in one circuit and charged by the current of one dynamo. It will thus be seen that the dynamo may be made to do double duty, charging batteries by day for use in connection with the incandescence lamps and supplying arc lamps direct, at night. The E. M. F.

of each Brush cell is about two volts. For electric lighting, they are generally prepared in batteries of twenty or more cells. An automatic current "manipulator" or switch is provided with each Brush battery and is arranged so as to retain the battery in circuit until it is charged and then to disconnect it from the circuit. When the charge has been exhausted to a certain point, it brings the battery into the circuit again and holds it till it has been recharged and then cuts it out as before. The same operation is repeated with every battery in circuit. The operation is automatic. Each battery has a clock attached, which registers the time that the charging current has been passing through the cells. The incandescence lamps are connected with the batteries through the "manipulator," as shown in Fig. 197. The quantity of electricity capable of being "stored" may be increased by increasing the number of cells and the size of the plates.

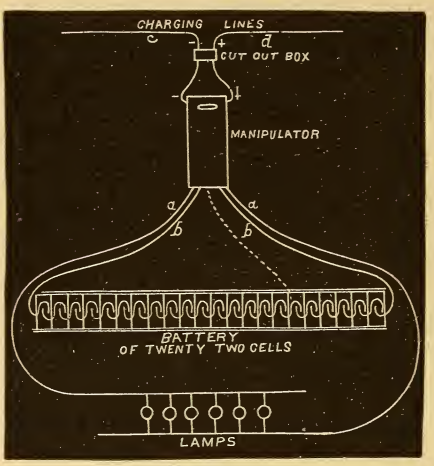


FIG. 197.

416. Magnetic Effects of the Electric Current.—Any conductor is rendered magnetic by passing a current of electricity through it. A common needle may be magnetized by winding about it an insulated copper wire and discharging a Leyden jar through the wire. We have already seen that a bar of soft iron may be temporarily magnetized by the influence of the voltaic current. It may be further shown by the action of the bar and helix.

(*a.*) This apparatus consists of a movable bar of soft iron surrounded by a coil of insulated copper wire (Fig. 198). When the wire of the coil is placed in the closed circuit of a battery, the iron bar becomes

strongly magnetized; when the circuit is broken, the bar instantly loses its magnetic power. The bar may be a straight piece of stout iron wire; the helix may be made by winding insulated copper wire upon a piece of glass tubing large enough to admit the wire and not quite as long as the iron.

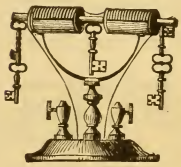


FIG. 198.

(*b.*) A good helix, convenient for many purposes, may be made upon an ordinary wooden spool. With a sharp knife, make the shank of the spool as thin as possible and then wind the spool full of insulated copper wire about as large as ordinary broom or stove-pipe wire. The iron bar must be small enough to pass easily through the hole in the spool and long enough to project a little ways beyond each end.

(*c.*) Either of these helices may be placed in the circuit of a cell and held in a vertical position, when it will act as a "sucking" magnet. The movable iron core will be held in mid-air "without any visible means of support."

(*d.*) The "helix and ring armature" is shown in Fig. 199. The armature is of soft iron divided into two semicircles with brass handles. When the helix is placed in a closed circuit, the semicircles resist a considerable force tending to draw them apart; when the circuit is broken, they fall asunder of their own weight. The iron ring may be made without handles by any blacksmith. Stout cords will answer for handles. The helix may be made by winding insulated wire upon a pasteboard cylinder an inch or an inch and a half long. There should be four or five layers of stout, copper wire which may be tied together with strings passing through the hole in the helix.

FIG. 199.

(*e.*) Such temporary magnets as these are called electro-magnets. The subject of electro-magnets will be further considered in §§ 442–448.

417. Deflection of the Magnetic Needle.—We have already seen that the voltaic current has a marked effect in turning the magnetic needle from its north and south position, tending to place the needle at right angles to the direction of the current. This may be easily shown by Oersted's apparatus represented in Fig. 200. It

consists of a magnetic needle and a brass wire frame with three pole-cups, permitting the current to be passed over, under, or around the magnet. *The space immediately surrounding a wire carrying an electric current is a field of magnetic force as truly as is the space around a magnetized body* (§ 433).

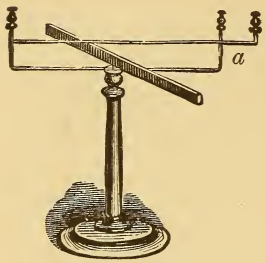


FIG. 200.

(*a.*) If the current pass *above* the needle from north to south, the north-seeking or — end of the magnet will be deflected toward the east; if it pass from south to north, the — end of the needle will be deflected toward the west. If the current pass *below* the needle, the deflections will be the opposite of those just mentioned. The wires are insulated where they cross at *a*.

418. The Astatic Galvanometer.—This galvanometer depends upon the principles set forth in the last paragraph. *It is a very delicate instrument for detecting the presence of an electric current and determining its direction and strength.* In Oersted's apparatus, the needle is heavy and a considerable force is needed to set it in motion; in the galvanometer, the needle is very light and suspended so as to turn easily. In Oersted's apparatus, the needle is held in the magnetic meridian by the directive influence of the earth; in the galvanometer, this is obviated almost wholly by the use of an astatic needle (§ 439). In Oersted's apparatus, the current makes but a single course about the needle; in the galvanometer, the wire is insulated and coiled many times about the needle; thus the effect is multiplied. One of the needles is within the coil while the other swings above it, the two being connected by a vertical axis passing through an appro-

priate slit in the coil. If both needles were within the coil, since their poles are reversed, the same current would tend to deflect them in opposite directions and thus the action of one needle would neutralize that of the other. The astatic needle is suspended by an untwisted silk fibre from a hook which may be lowered when the instrument is not in use until the upper needle rests upon the dial plate beneath it. The ends of the coiled wire are connected with binding screws; leveling screws are provided, by means of which the instrument may be adjusted so that the needles shall swing clear of all obstructions. A glass cover protects from dust and disturbance by air currents. The instrument is represented in Fig. 201.

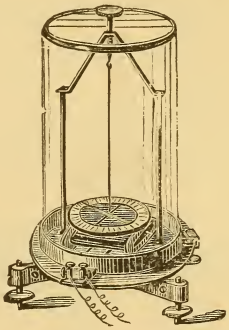


FIG. 201.

(*a.*) When the deflections of the astatic galvanometer are less than 10° or 15°, they are very nearly proportional to the strengths of the currents that produce said deflections. A current that deflects the needle 6° is about three times as strong as one that deflects it 2°.

(*b.*) That a galvanometer shall be good, it must be able to measure the strength of the current in some certain way. It must be adapted to the currents to be measured by it. A galvanometer fitted for the measurement of small currents (*e. g.*, five or six milliamperes) would not be suitable for measuring a ten ampere arc electric light current. If the current to be measured has passed through a circuit of great resistance (*e. g.*, several miles of telegraph wire), a short-coil galvanometer consisting of only a few turns of wire will not answer; a long-coil galvanometer, with many turns of wire about the needle, must be used. Hence, it will be seen that different kinds of galvanometers are needed for different kinds of work. (See Appendix L.)

Experiment 80.—Connect an iron and a German silver wire to the binding posts of a sensitive, short-coil, astatic galvanometer. Twist the free ends of the wires together and heat the junction in

the flame of an alcohol lamp. *The deflection of the galvanometer-needle will show that an electric current is traversing the circuit.* Cool the junction with a piece of ice. The galvanometer will show that a second current is flowing in the opposite direction.

419. Thermo-Electricity. — *If a circuit be made of two metals and one of the junctions be heated or chilled, a current of electricity is produced.*

(*a.*) This may be further illustrated by the apparatus shown in Fig. 202. The upper bar, *m n*, having its ends bent, is made of copper; the lower, *o p*, is of bismuth. This rectangular frame is to be placed in the magnetic meridian and a magnetic needle placed within it. Upon heating one of the junctions, a current will be produced, the existence of which is satisfactorily shown by the deflection of the needle as indicated in the figure. The junction may be chilled with a piece of ice or by placing upon it some cotton wool moistened with ether. In this case, a current, opposite in direction to the first, will be produced; the needle will be turned the other way. The frame may be simplified by bending a strip of copper twice at right angles to make the top, bottom and one end of the frame, the other end being a cylinder of bismuth. But the form shown in Fig. 202 is preferable, as the same junction may be heated by the lamp below or chilled by laying a piece of ice on the upper side.

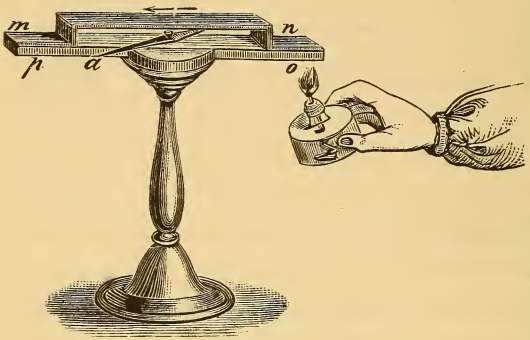


FIG. 202.

420. A Thermo-electric Pair.—If a bar of antimony, *A*, be soldered to a bar of bismuth, *B*, and the free ends joined by a wire, we evidently have a circuit

equivalent to the one considered in the last paragraph. When the junction, *C*, is heated, a current will pass, from bismuth to antimony across the junction and from antimony to bismuth through the wire, as shown in Fig. 203.

(*a.*) The arrangement is analogous to a voltaic element, the antimony representing the — plate and carrying the + electrode, the bismuth representing the + plate and carrying the — electrode, while the solder takes the place of the liquid. The E. M. F. of an antimony-bismuth pair for 1° C. difference of temperature is about 117 microvolts. Just as a number of voltaic elements may be connected, so may a number of thermo-electric pairs be connected to form a thermo-electric series.

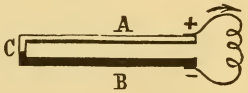


FIG. 203.

421. The Thermo-electric Pile. — Several thermo-electric pairs, generally five, six, or seven, are arranged in a vertical series, as shown in Fig. 204, the intervening spaces being much reduced, the successive bars separated by strips of varnished paper only and the wire connection omitted. A similar series may be united to this by soldering the free end of the antimony bar of one series to the free end of the bismuth bar of the other, the two series being separated by a strip of varnished paper. Any desirable number of such series may be thus united, compactly insulated and set in a metal frame so that only the soldered ends are open to view. The free end of the antimony bar, representing the + electrode, and the free end of the bismuth bar, representing the — electrode, are connected with binding screws, which may be connected with a sensitive short-coil galvanometer. The thermo-electric

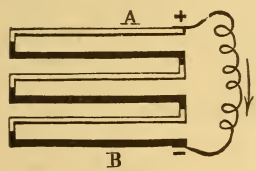


FIG. 204.

pile, with the addition of conical reflectors, is shown in Fig. 205. A change of temperature at either exposed face of the pile produces a feeble current of electricity which is manifested by the movement of the needle of the galvanometer. The instrument is much used in scientific work for detecting differences in temperature, being much more sensitive than the mercury thermometer.

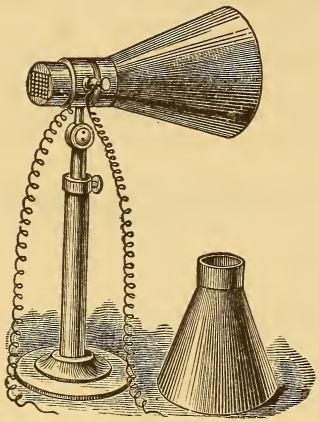


FIG. 205.

422. The Peltier Effect.—When an electric current passes over a junction from antimony to bismuth, there is an evolution of heat at the junction, the temperature of which rises. When the current passes in the opposite direction (from bismuth to antimony), there is an absorption of heat and the temperature of the junction falls. In other words, if the current be sent through the circuit in the direction in which the thermo-electromotive force would naturally send it, the heated junctions will be cooled and the cooled junctions will be heated.

EXERCISES.

1. (*a.*) Draw a figure of a simple voltaic element. (*b.*) State what is meant by the electric current. (*c.*) Indicate, upon the figure, the direction of the current. (*d.*) What are the electrodes? (*e.*) Indicate them by their proper signs upon the figure.

2. (*a.*) Describe or figure a high resistance battery of Grove's elements. (*b.*) A low resistance battery of Bunsen's elements. (*c.*) What is the peculiar advantage of the Daniell's battery?

3. Describe an experiment illustrating the heating effects of current electricity.

4. (*a.*) How may a very feeble current be detected? (*b.*) Describe the apparatus used. (*c.*) Mention the features contributing to its delicacy.

5. (*a.*) If the resistance of one mile of a certain electric light wire is 3.58 ohms, what is the resistance of 4.4 miles of the same wire? (*b.*) The resistance of a certain wire is 5 ohms per 100 yd. What length of the same wire will have a resistance of 13.2 ohms?

Ans. (*a.*) 15.75 ohms. (*b.*) 264 yd.

6. What is the resistance of a mile of copper wire that has a diameter of 65 mils if the resistance of a mile of copper wire 80 mils in diameter is 8.29 ohms? *Ans.* 12.56 ohms.

7. If the resistance of 700 yd. of a certain wire is 0.91 ohm, what is the resistance of 1,320 yd.? *Ans.* 1.72 ohm.

8. (*a.*) Define electrolyte. (*b.*) What term is applied to chemical decomposition when effected by means of an electric current? (*c.*) How would you go about the task of determining for yourself the electro-chemical nature of a substance?

9. The resistance of a certain wire is 4.55 ohms. The resistance of a mile of the same wire is 1.3 ohms. What is the length of the first wire? *Ans.* 3.5 mi.

10. The resistance of a mile of copper wire 70 mils in diameter is 10.82 ohms. What is the diameter of a copper wire a mile long and having a resistance of 23 ohms? *Ans.* 0.048 inch or 48 mils.

11. What should be the length of a silver wire so that it may have the same resistance as 10 inches of copper wire of the same thickness, the conductivity of silver being 1.0467 times that of copper?

12. Find the resistance, at the freezing temperature, of 20 *m.* of German silver wire weighing 52.5 grams, having given that the resistance, at the same temperature, of a wire of the same material 1 *m.* long and weighing 1 *g.* is 1.85 ohms. *Ans.* 14 1 ohm.

13. When a piece of fine platinum wire and a galvanometer are put in the circuit of a galvanic cell, the needle is deflected. Remove the platinum wire and close the circuit with stout copper wire; the needle is deflected more than before. Explain.

14. Find the resistance of 500 yd. of copper wire 165 mils in diameter, the resistance of one mile of copper wire 230 mils in diameter being one ohm. *Ans.* 0.55 ohm.

15. If 1,000 ft. of wire 95 mils in diameter have a resistance of 1.15 ohm, what is the diameter of a wire of the same material that has a resistance of 10.09 ohms per 1,000 ft.? *Ans.* 32 mils.

16. Under what circumstances is it desirable to arrange cells as shown in Fig. 206?

17. A copper wire 6 *m.* long has a diameter of 0.74 *mm.* What is the length of a copper wire of 1 *mm.* diameter that has the same electrical resistance? *Ans.* 10.957 *m.*

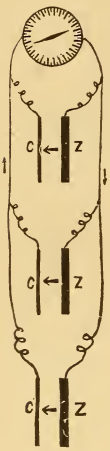


FIG. 206.

18. Given 8 cells, each with an E. M. F. of 2 volts and an internal resistance of 8 ohms. The resistance of the external circuit is to be 16 ohms. How shall the cells be arranged to give maximum current and what will that current be? *Ans.* 0.25 ampere.

19. What is the length of an iron wire having a sectional area of 4 *sq. mm.* and the same resistance as a copper wire 1,000 yd. long, the latter having a sectional area of 1 *sq. mm.*, the conductivity of iron being $\frac{1}{7}$ that of copper? *Ans.* $571\frac{3}{7}$ yd.

20. Two incandescence lamps of 31 and 37 ohms respectively are placed abreast in a circuit. Find the joint resistance of the two lamps. *Ans.* 16.87 ohms.

21. How thick must an iron wire be so that it and a copper wire that has the same length and a diameter of 2.5 *mm.* shall have the same resistance, the resistance of iron being 7 times that of copper? *Ans.* 6.61 *mm.*

22. How many coulombs will be furnished by the consumption of 20 *g.* of zinc?

23. What weight of zinc must be consumed in each cell of a voltaic battery of 3 Daniell's cells to enable the electrolysis of 9 *g.* of water? (Neglect loss by local action.) *Ans.* About 32.5 *g.*

24. What weight of copper will be deposited in each cell of the battery mentioned in the last problem? *Ans.* About 31.5 *g.*

25. Three wires, the respective resistances of which are 5, 7 and 9 ohms are joined in multiple arc. Find the resultant resistance of this compound conductor. *Ans.* 2.2 ohms.

26. What is the necessary E. M. F. of a dynamo that is to furnish a 10 ampere current for 60 arc lamps (in series), each of which has a resistance of 4.5 ohms, the resistance of the line wire being 10 ohms and the internal resistance of the dynamo being 22 ohms?

27. A piece of zinc, at the lower end of which a piece of copper wire is fixed, is suspended in a glass jar containing a solution of acetate of lead (sugar of lead). After a few hours, a deposit of lead in tree-like form grows downward from the copper wire. Explain this.

28. Liquids increase in conductivity with an increase of temper-

ature. Will a given battery give a stronger current at 0° C. or at 20° C.?

29. What should be the length of a lead wire so that it may have the same resistance as 10 inches of copper wire of the same thickness, the conductivity of lead being 0.0923 times that of copper?

30. Four wires are joined together in multiple arc, their resistances being 5.5, 18, 3.7 and 2.9 ohms respectively. Find the resultant resistance of the compound conductor thus formed.

Ans. 1.17 ohm.

HONORARY PROBLEM.

31. Find the number of incandescence lamps that may be worked in multiple arc by a dynamo-electric machine that has an internal resistance of 0.032 ohm. The E. M. F. of the dynamo is 55 volts and the resistance of each lamp is 28 ohms. The current must be 1.6 amperes in each lamp. *Ans.* 199 lamps.

Recapitulation.—To be amplified by the pupil for review.

- CURRENT ELECTRICITY.
  - CHEMICAL ACTION.
    - VOLTAIC.....
      - CELL.....
        - *One Liquid*.. — Smee's. Potassium di-chromate. Leclanché.
        - *Two Liquids.* — Daniell's. Callaud's. Grove's. Bunsen's.
        - *Joined*..... — Tandem. Abreast. Best Method.
      - SOURCE OF ENERGY.
      - BATTERY... — *High Internal Resistance.* *Low Internal Resistance.* *Requisites.*
      - CURRENT... — *Direction*; *Strength*..... — Unit. Ohm's Law.
    - CIRCUIT..... — Simple. Divided. Shunt.
    - SIGN OF..... — Plate. Pole. Electrode. — *Anode.* *Kathode.*
    - POTENTIAL; FALL OF E. M. F. — *Unit.* *Measurement.*
    - RESISTANCE .... — External. Internal. Laws. Unit. Measurement. Long and Short-Coil Instruments.
    - QUANTITY;..... UNIT.
    - LOCAL ACTION. — Cause. Remedy.
    - POLARIZATION. — Cause. Remedy.
  - EFFECTS.
    - MECHANICAL.
    - THERMAL;..... RELATION TO RESISTANCE.
    - LUMINOUS.
    - PHYSIOLOGICAL.
    - CHEMICAL... ...
      - ELECTROLYSIS. — *Anion.* *Kathion.* — Ions.
      - ELECTRO-METALLURGY.
      - ELECTRO-CHEMICAL SERIES.
      - E. M. F. OF POLARIZATION.
      - SECONDARY BATTERIES.. — *Faure's.* *Brush's.* *Uses.* *Advantages.*
    - MAGNETIC..... — Electro-Magnets. Electric Telegraph. Galvanometer.
  - THERMO-ELECTRICITY.

(*For Induced Currents, see Section V. of this Chapter.*)

SECTION IV.

MAGNETISM.

423. Natural Magnets.—One of the most valuable iron ores is called magnetite (Fe_3O_4). Occasional specimens of magnetite will attract filings and other pieces of iron. *Such a specimen is called a lodestone.* It is a natural magnet.

424. Artificial Magnets.—Artificial magnets are either temporary or permanent. A temporary magnet is usually made of soft iron and is called an electromagnet. A permanent magnet is usually made of steel. Artificial magnets have all the properties of natural magnets and are more powerful and convenient. They are, therefore, preferable for general use. The most common forms are the straight or *bar* magnet and the *horseshoe* magnet. The first of these is a straight bar of iron or steel; the second is shaped like a letter U, the ends being thus brought near together, as shown in Fig. 207. A piece of iron placed across the two poles of a horseshoe magnet is called an *armature.* We have already learned how to make artificial magnets.

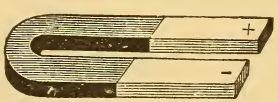


FIG. 207.

425. Retentivity.—It is more difficult to get the magnetism into steel than into iron. It is also more diffi-

cult to get it out. *This power of resisting magnetization or demagnetization is called coercive force or retentivity.* The harder the steel, the greater its retentivity. Soft wrought iron has but little retentivity.

426. Distribution of Magnetism.—If a bar magnet be rolled in iron filings and then withdrawn, the

FIG. 208.

filings cling to the ends of the bar but not to the middle. This form of attraction is not evenly distributed throughout the bar. *It is greatest at or near the ends. These points of greatest attraction are called the poles of the magnet.* It is impossible, by any known means, to develop one magnetic pole without simultane-

ously developing another pole of opposite sign. The middle of the magnet does not attract iron and is called the *equator or neutral point.*

Experiment 81.—Bring either end of a bar magnet near the end of a floating piece of iron, AB; the iron is attracted. Bring the same end of the magnet near the middle of the iron; the iron is attracted. Bring the same end of the magnet near the other end of the iron; the iron is attracted. Repeat the experiments with the other end of the magnet; in each case, the iron is attracted.

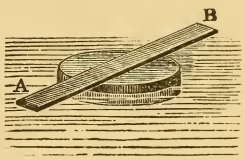


FIG. 209.

427. Attraction between a Magnet and Iron.—*Either pole of a magnet will attract ordinary iron.*

Experiment 82.—Freely suspend three bar magnets, A, B and C, at some distance from each other. This may be done by placing each magnet in a stout paper stirrup supported by a cord or horse-hair or upon a board or cork floating on water. (See Fig. 209.) *When they have come to rest, each will lie in a north and south line.* Magnets for this experiment may be made by magnetizing (§ 448) three stout knitting-needles. If there is any electric light apparatus in your neighborhood in charge of a good-natured man, he will probably magnetize the needles for you. Each needle may be suspended by means of a triangular piece of stiff writing-paper. Pass the needle through the paper near the lower corners; at the other corner, affix, by wax, the end of a horse-hair. The poles may be indicated by little bits of red and of white paper, fastened by means of wax to the ends of the needles. Mark the north-seeking poles, $-$ and the south-seeking poles, $+$.

428. Characteristics of Magnets.—*Magnets are chiefly characterized by the property of attracting iron and by a tendency to assume a particular direction of position when freely suspended.*

Experiment 83.—(*a.*) Take magnet A of Experiment 82 from its

support and bring its + end near the — end of *B* or *C*. Notice the attraction.

(*b.*) Bring the + end of *A* near the + end of *B* or *C*. Notice the repulsion.

(*c.*) Bring the — end of *A* near the — end of *B* or *C*. Notice the repulsion.

(*d.*) Bring the — end of *A* near the + end of *B* or *C*. Notice the attraction.

(*e.*) From (*a.*), we learned that the — ends of *B* and *C* were each attracted by the + end of *A*. Bring the — end of *B* near the — end of *C*. Notice that they now repel.

(*f.*) From (*b.*), we learned that the + ends of *B* and *C* were each repelled by the + end of *A*. Bring the + end of *B* near the + end *C*. Notice that they now repel.

(*g.*) In similar manner, show that the + end of *B* will attract the — end of *C*; that the — end of *B* will attract the + end of *C*.

Record the results of your experiments in tabular form thus:

(*a.*) + attracts —.	(*b.*) + repels +.
(*d.*) — attracts +.	(*c.*) — repels —.
etc.	*etc.*

Experiment 84.—Magnetize a number of fine sewing-needles by drawing the + end of a bar magnet three or four times from the eye to the point of each. Cut several small corks into slices about an eighth of an inch thick. Through each cork disc, push a needle up to its eye and place them in a round dish of water. These little magnets have their like poles presented to each other and they mutually repel. Bring the bar magnet, with its + end downward, over the needles; they will be driven to the sides. Similarly, bring the — end over them; they will be attracted toward the centre.

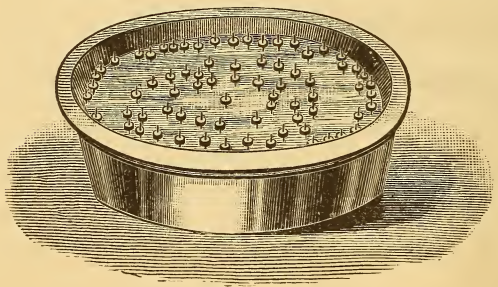


FIG. 210.

429. Laws of Magnets.—(1.) *Every magnet*

has two similar poles; like poles repel each other; unlike poles attract each other.

(2.) *Magnetic force, like other forms of attraction and repulsion, varies inversely as the square of the distance.*

Experiment 85.—Dip one of the magnetized knitting-needles into iron filings. Notice that filings cling to the ends, near the paper discs, but that none cling to the middle. Break the needle in the middle and dip each piece into iron filings. Notice that the unmarked ends, which were at the middle of the unbroken magnet, now attract iron filings as well as do the marked ends. *Poles have been developed in parts of the needle that previously showed no magnetic attraction.*

430. Effect of Breaking a Magnet.—If a magnet be broken, each piece becomes a magnet with two poles and an equator of its own. These pieces may be repeatedly subdivided and each fragment will be a perfect magnet.

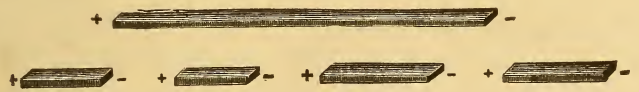


FIG. 211.

It is probable that every molecule has its poles or is polarized and that, could one be isolated, it would be a perfect magnet. We may, thus, conceive a magnet as made up of molecules each of which is a magnet, the action of the molar magnet being due to the combined action of all the molecular magnets of which it is composed.

431. Magnetized, Magnetic and Diamagnetic Substances.—A *magnetized* body is one that

can be made to repel a pole of a freely suspended magnet. Substances that are attracted by a magnet are called *magnetic; e.g.*, iron or steel and nickel. Substances that are repelled by a magnet are called *diamagnetic; e.g.*, bismuth, antimony, zinc, tin, mercury, lead, silver, copper, gold and arsenic. Of these, iron is by far the most magnetic, while bismuth is the most diamagnetic. The magnetic properties of iron or steel are easily shown; diamagnetic properties require a powerful magnet for satisfactory illustration.

Experiment 86.—Wrap a bar magnet in a piece of cloth. With it, attract and repel the poles of a suspended magnet.

Experiment 87.—Repeat the last experiment, holding a slate or sheet of zinc between the two magnets.

Experiment 88.—Put one piece of the broken magnet into a bottle; cork the bottle tightly. With it, attract and repel the poles of a suspended magnet.

432. Magnetic Screens.—*Nothing but a magnetic body can cut off the inductive action of a magnet.* If a small magnet be suspended inside a hollow iron ball, no outside magnet will affect it.

Experiment 89.—With the end of a good bar magnet, write your name upon the blade of a handsaw. The invisible characters may be made visible by sifting fine iron filings upon the blade.

Experiment 90.—Place a piece of card-board or rough drawing paper over a good bar magnet. Sift fine iron filings through a piece of muslin upon the card-board and tap it lightly. The iron particles will move and arrange themselves in well defined curved lines. (See Fig. 212.) By using two bar magnets placed side by side, *first*, with like poles near each other and, *secondly*, with unlike poles near each other, their combined effect on the iron filings may be easily observed. The figures will be widely different.

433. Magnetic Field.—A magnet seems to be surrounded by an atmosphere of magnetic influence called *the magnetic field.* (See § 450*d* and Appendix N.) The magnetic curves, formed in the above experiment, are very interesting and instructive for they show the direction of *the lines of magnetic force.* The filings in any one of these curves are temporary magnets with

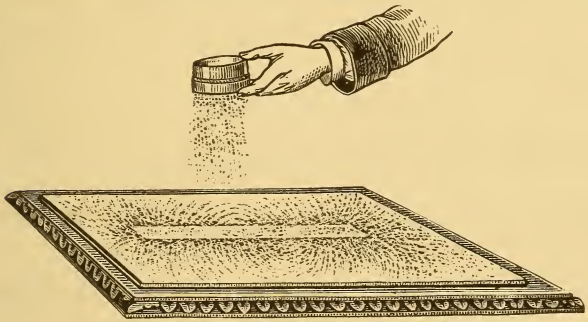


FIG. 212.

adjoining poles opposite and therefore attracting. If a small magnetic needle be suspended over the card board at any point, its length will tend to lie in the direction of the lines of magnetic force at that point as mapped out by the iron filings.

(*a.*) The figures may be permanently fixed by using a sheet of glass that has been gummed and dried, instead of the sheet of paper. The filings are sifted evenly over the surface; then the glass is tapped; then a jet of steam is caused to play gently above the sheet, softening the surface of the gum, which, as it hardens, fixes the filings in their places.

(*b.*) Since the lines of force are made of little magnetic particles that set themselves thus in obedience to the attractions and repulsions in the field, they represent the resultant direction of said forces at each point. They map out the magnetic field, showing the direction of the magnetic force by their position and its intensity by

their number. If a small — pole could be obtained alone and put down on any one of these lines of force, it would tend to move along that line from + to − ; a single + pole would tend to move along the line in an opposite direction.

Experiment 91.—Rub *one end* of a steel pen against the end of a magnet. Dip the pen into iron filings and notice that the newly made magnet has a pole at *each end.* Determine the sign of each of these poles, as indicated in Experiment 82.

434. Magnetization by Contact.—*A bar of iron or steel may be magnetized by rubbing it against a magnet.* Pure or soft iron is easily magnetized but quickly loses its magnetism when the magnetizing influence is removed. Hardened steel is magnetized with more difficulty but retains its magnetism after the removal of the magnetizing influence.

Experiment 92.—Move the point of an unmagnetized steel pen to and fro very near one end of a magnet but without touching it to the magnet. Dip the pen into iron filings and determine whether or not it has been magnetized. If it has, determine the sign of each pole, as in the last experiment and notice whether the point of the pen is of the same polarity as the end of the magnet near which it was moved.

Experiment 93.—Bring a short bar of soft iron, *I,* very near a strong bar magnet, *M,* end to end, as shown in the figure. Sprinkle

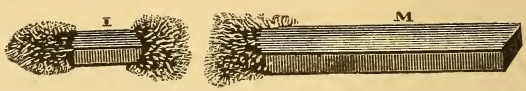


FIG. 213.

iron filings over the ends of the iron bar and they will cling as they would to a magnet. *The iron bar is a magnet, while it remains in this position.*

435. Magnetic Induction.—If the end of a bar of soft iron be brought near one of the poles of a strong

magnet, *the iron becomes, for the time being, a magnet.* The poles of the temporary magnet will be opposite to those of the permanent magnet, *i.e.*, if the + or positive pole of the magnet be presented to the iron bar, it will develop a — or negative pole in the nearest end of the iron bar and a + pole at the further end. Bring the iron bar nearer the magnet and this effect will be increased. Actual contact is not necessary, but when the iron and the magnet touch, the magnetizing force is the greatest. If a steel bar be used instead of an iron bar, it will be permanently instead of temporarily magnetized. *The iron or the steel is induced to become a magnet by the influence of the magnet used. It is said to be magnetized by induction.* This, like other forms of attraction, varies inversely as the square of the distance. We have already seen that magnetic induction takes place in certain directions called lines of magnetic force (§ 433.)

Experiment 94.—Bring a soft iron ring to the end of a magnet. It will be supported. Bring a second ring into contact with the first ring and it will be supported. In this way, quite a number of rings may be supported, each ring being magnetized by the bar or ring magnet above it. Of course, the attractive force is continually weakening from the first to the last ring. Support the upper ring upon your finger and remove the magnet. Each ring ceases to be a magnet and the chain is broken into its separate links. Vary the experiment by using, instead of the rings: (1,) Soft iron nails; (2,) Steel sewing-needles; and see if there is any difference in the results.

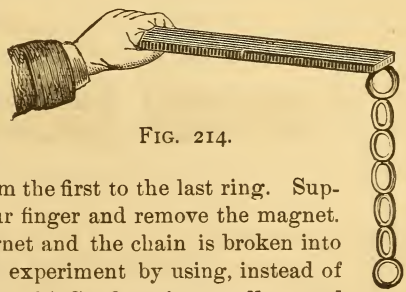


FIG. 214.

Experiment 95.—Suspend an iron key from the positive end of a bar magnet. The key is inductively magnetized, the relation of

its poles to each other and to the magnet being as shown in Fig. 215. A second bar magnet of about the same power, with its poles opposite, is moved along the first magnet. *When the — end of the second magnet comes over the key, the key drops.*

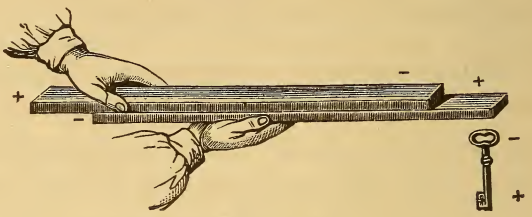


FIG. 215.

The first magnet tends to induce a — pole at the upper end of the key. The second magnet tends to induce a + pole at the same point. The effect of each magnet neutralizes that of the other.

Experiment 96.—Magnetize a piece of watch spring about six inches long (easily obtainable at the watch repairer's) by drawing it several times between the thumb and the end of a magnet. Dip it into iron filings. Lift it carefully with its load. Bring the poles of the spring magnet together, bending the magnet into a ring. *The magnet drops its load.*

FIG. 216.

436. Induction Precedes Attraction.—We now see why a magnet attracts ordinary iron; it first magnetizes it and then attracts it. The attraction between unlike poles is greater than the repulsion between like poles because of the smaller distance between them. Compare § 336.

Experiment 97.—Test a common fire poker for magnetism by bringing a small magnetic needle near its ends and seeing whether the poker *repels* either pole of the compass needle or whether the two ends of the poker attract *different* poles of the needle. If the poker is not even slightly magnetic, place it with its upper end sloping toward the south so as

to make an angle of a little less than half a right angle. In other words, place it in the position assumed by the dipping needle. (§ 439.) While the poker is in this position, strike it a few blows with a wooden block or mallet. Test it again for magnetism. A steel poker that has usually stood in a nearly vertical position may, thus, often be shown to have acquired magnetism.

437. The Earth is a Magnet.—The earth acts like a huge magnet in determining the direction of compass and dipping needles. Its inductive influence, as shown in the last experiment, strengthens the belief that it has such action. If a small dipping needle be placed over the — end of a bar magnet, the needle will take a vertical position with its + end down. As the needle is moved toward the other end of the bar, it turns from its

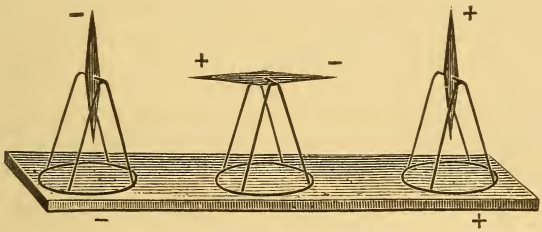


FIG. 217.

vertical position. When over the neutral line, the needle is horizontal. As it approaches the + end of the magnet, the needle again becomes vertical, but the — end of the needle is drawn down. If a dipping needle be carried from far southern to far northern latitudes, it will act in a similar way. Many facts seem to teach that *the earth is a great magnet with magnetic poles near its geographical poles.* The magnetic pole in the northern hemisphere was found in 1832 by Capt. Ross. It was then a little north and west of Hudson's Bay, in latitude

70° 05′ N., and longitude 96° 45′ W. A place in the southern hemisphere has been found where the dipping needle is *nearly* vertical.

438. Names of Magnetic Poles.—We have now learned to regard the earth as a huge magnet, with one pole in the northern hemisphere and one in the southern. Since unlike poles attract each other, it follows that *the earth's magnetic pole situated in the northern hemisphere is opposite, in kind, to the end of a magnetic needle that points to the north.* From this fact, great confusion of nomenclature has arisen. We have spoken of the end of the needle that points north as − or negative. Following this nomenclature, the northern magnetic pole of the earth must be + or positive. But popular usage calls the north-seeking end of the needle the north pole and the other end the south pole. This introduces great confusion when we wish to speak of the magnetic poles of the earth. The nomenclature that we have adopted obviates this confusion.

Experiment 98.—Make a horizontal needle of a piece of watch spring about six inches long and straightened by drawing it between thumb and finger. Heat the middle of the needle to redness in a flame and bend it double. Bend the ends back into a line with each other, as shown in Fig. 218. Magnetize each end separately and oppositely. Wind a waxed thread around the short bend at the middle to form a socket and balance the needle upon the point of a sewing-needle thrust into a cork for support. A little filing, clipping with shears or loading with wax may be necessary to make it balance. The needle will point north and south.

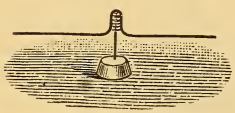


FIG. 218.

Experiment 99.—By means of a fine wire fork, gently lay one of the magnetized sewing-needles of Experiment 84 on the surface of water. It will float without any cork or similar support and will assume a north and south position. It may be considered the needle of a small compass.

439. Magnetic Needles.—*A small bar magnet suspended in such a manner as to allow it to assume its chosen position is a magnetic needle.* (See Appendix J.)

(*a.*) If it be free to move in a horizontal plane, it is a horizontal needle; *e. g.*, the mariner's or the surveyor's compass (Fig. 219). It will come to rest pointing nearly north and south. If the magnet be free to move in a vertical plane, it constitutes a vertical or dipping needle (Fig. 220). Two magnets fastened to a common axis but having their poles reversed constitute an astatic needle (Fig. 221). An astatic needle assumes no particular direction with respect to the earth if the two needles are equally magnetized. (§ 418.)

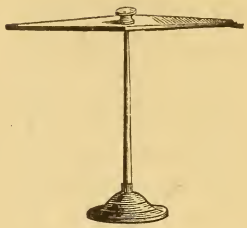


FIG 219.

(*b.*) Make a dipping needle by thrusting a knitting-needle through a cork so that the cork shall be at the middle of the needle. Thrust through the cork, at right angles to the knitting-needle, half a knitting-needle, or a sewing-needle, for an axis. Support the ends of the axis upon the edges of two glass goblets or other convenient objects. Push the knitting-needle through the cork so that it will balance upon the axis like a scale-beam. Magnetize the knitting-needle and notice the *dip*.

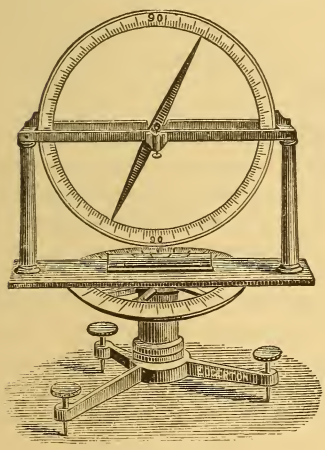


FIG. 220.

(*c.*) A magnetized sewing-needle, suspended near its middle (at its centre of gravity) by a fine thread or hair or an untwisted fibre will serve as a dipping needle. It should first be suspended so as to hang horizontal and magnetized afterward. A simple form of dipping needle is represented in Fig. 222.

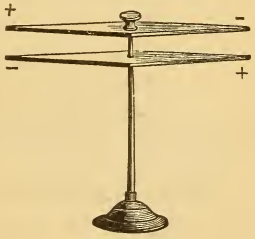


FIG. 221.

440. Inclination or Dip.—*The angle that a dipping needle makes with a horizontal line is called its inclination or dip.* The angle in question is indicated

by the dotted arc of Fig. 222. At the magnetic poles, the inclination is 90°; at the magnetic equator, there is no inclination. The inclination at any given place is not greatly different from the latitude of that place.

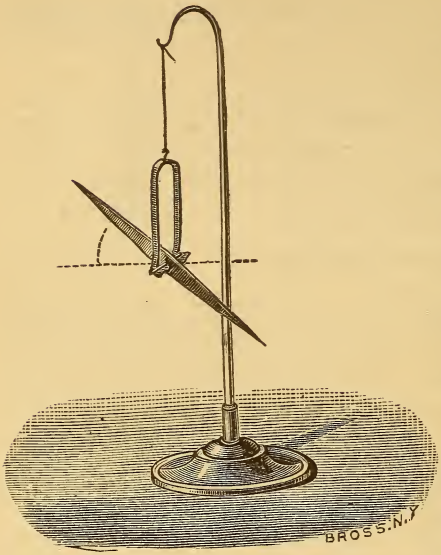


FIG. 222.

(*a.*) Experiments for inclination are difficult of execution without special apparatus. It is difficult to make a needle turn about a point exactly coincident with its centre of gravity. In rough experiments, there is danger that the magnetic effect will be masked by the effect of gravity.

In winter, the dipper is seen in this position, east or north-east of the North Star.
NORTH STAR
GREAT DIPPER
a
β
In summer, the dipper is seen in this position, west or north-west of the North Star.

FIG. 223.

Experiment 100.—Set two stakes so that a string joining them will point toward the North Star. The string will run north and south or nearly enough so for our purpose. Place a long magnet suspended as a needle under or over the string. Looking downward at the magnet and the string, it will probably be found that the needle and the string do not point in the same direction. The North Star may be easily found any evening in the direction indicated by "The Pointers" of the well known constellation, "The Great Dipper." "The Pointers" are the two stars marked by the Greek letters α and β in Fig. 223.

441. Declination or Variation.—The magnetic needle, at most places, does not lie in an exact north and south line. *The angle that the needle makes with the geographical meridian is its declination or variation.* A line drawn through all places where the needle points to the true north is called *a Line of no Variation.* Such a line, nearly straight, passes near Cape Hatteras, a little east of Cleveland, Ohio, through Lake Erie and Lake Huron. It is now slowly moving westward. At all places east of the Line of no Variation, the — end of the needle points west of the true north; at all places west of the Line of no Variation, the variation is easterly. The further a place is from this line, the greater the declination, it being 18° in Maine and more than 20° in Oregon.

(*a.*) In order that ships may steer safely by the compass, magnetic charts are prepared. The declination at various places is properly indicated on the chart. The surveyor must recognize not only the declination of his needle but also the changes in declination. Otherwise he would not be able properly to "run the lines" of a given piece of land from the description given in an old deed.

FIG. 224.

Experiment 101.—Construct a floating cell of zinc and copper plates, about ¼ inch apart, the connecting wire being given an elongated spiral or *solenoid* form, and support it by a large, flat cork resting on the surface of a bowlful of acidu-

lated water, as shown in Fig. 224. The solenoid may be made by winding the middle part of about 3 yards of No. 20 insulated copper wire around a rod, half an inch in diameter, forming thus a coil, 4 or 5 inches long. The current will set the axis of the solenoid in a north and south direction as if it were a magnetic needle. By holding one end of a bar magnet near first one end and then the other end of the solenoid, it will be found that the latter exhibits magnetic polarity.

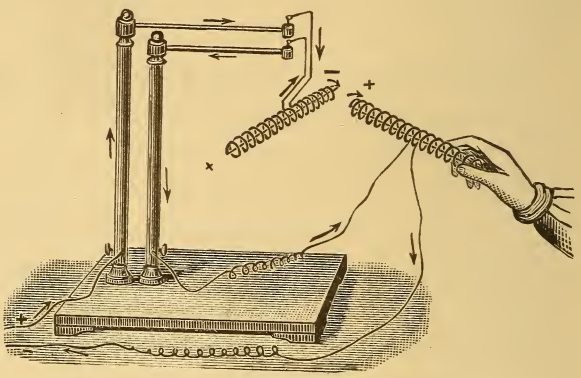


FIG. 225.

Experiment 102.—Support a solenoid by placing the extremities of its wire (bent into the same vertical axis) in two mercury cups, as shown in Fig. 225, or use the solenoid of the floating battery above described. Bring the end of a second solenoid successively to the ends of the first and notice the exhibition of magnetic polarity.

Experiment 103.—Send a current of electricity from the small cell, mentioned in Experiment 16, through its wire. Pour half a teaspoonful of iron filings upon a sheet of paper and bring the wire conductor of the cell into contact with the filings. Notice that the filings cling to the wire as though it were a magnet. Break the circuit and notice that the filings fall from the wire.

442. Electro-Magnets.—From these experiments, we see that while the wire conductor is carrying an electric current it has the properties of a magnet. We have already seen that, under similar circumstances, the conductor deflects a magnetic needle as if it were itself a

magnet. In fact, such a conductor is a temporary magnet. The magnetic effect is much increased if a considerable length of the conductor be made of insulated wire and wound into a coil, as shown in Fig. 226. Such a coil is called a *helix;* it is a magnet with a + pole at one end and a — pole at the other. It has an easily perceptible magnetic field. If a soft iron rod or core be introduced into the coil, it enters the magnetic field of the coil or helix and becomes a magnet. This combination of coil and core constitutes an electro-magnet and is more powerfully magnetic than the coil alone. *An electro-magnet is a bar of iron surrounded by a coil of insulated wire carrying a current of electricity.* It may be made more powerful than any permanent magnet but loses its power as soon as the current ceases to flow through its coil. The fact that the magnetism of this apparatus is under control adapts it to many important uses, such as electric bells and telegraphic instruments.

FIG. 226.

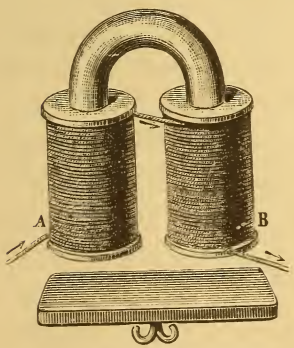


FIG. 227.

443. Forms of Electro-Magnets.—The bar of § 416, *a*, and the ring of Fig. 199, with their helices, are electro-magnets. The electro-magnet more often has the horse-shoe form shown in Fig. 227, so that the attraction of both poles may act upon the same

body at the same time. The middle of the bent bar is bare, the direction of the windings on the ends being such that, were the bar straightened, the current would move in the same direction round every part. More frequently, the two helices, *A* and *B*, have separate cores which are joined by a third straight piece into which the ends of the cores are screwed. An armature is often placed across the two poles of the magnet, as shown in the figure. Electro-magnets have been made capable of supporting several tons.

(*a.*) When the circuit is broken and the current thus interrupted, the iron is generally not *wholly* demagnetized. The small magnetism remaining is called *residual magnetism*. The residual magnetism seems to increase with the hardness and impurity of the iron. The cores of electro-magnets for some purposes are made of the softest and purest iron obtainable.

444. The Electric Telegraph. — The electric telegraph consists essentially of an electro-magnet and a "key" placed in the circuit of a battery. The key is an instrument by which the circuit may be easily broken or closed at will. The armature, *A*, of the "register" magnet, *M*, is supported by a spring, *S*, which lifts it when the circuit is broken. When the circuit is closed, the armature is drawn down by the attraction of the magnet. Thus, the armature may be made to vibrate up and down at the will of the person at the key. The

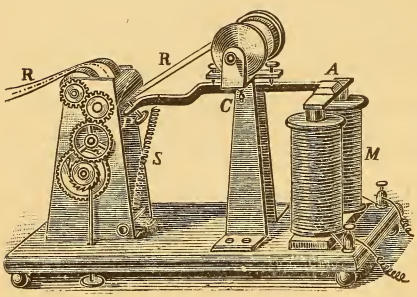


FIG. 228.

armature may act upon one arm of a lever, the other end of which, being provided with a style or pencil, *P*, may be pressed against a paper ribbon, *R*, drawn along by clockwork. Thus, the pencil may be made to record, upon the moving paper, a series of dots and lines at the pleasure of the operator at the key perhaps hundreds of miles away. When the two stations are several miles apart, one of the wires is dispensed with, the circuit being completed by connecting each station with the earth. This arrangement saves half the wire and nearly half the cost of the line. As the resistance of the earth is insignificant, there is the further saving of nearly half the battery otherwise necessary. Earth connections are often made by joining the wires to water or gas pipes that run into the ground. When the line is long, there is a battery at each end, the + electrode of one battery and the — electrode of the other battery being joined to the line wire. The same principle of communicating signals by making and breaking an electric circuit is used in fire and burglar alarms, hotel annunciators, *etc.*

445. Morse's Alphabet. — The inventor of the practical electric telegraph was an American, S. F. B. Morse. The code of signals devised by him is given below:

LETTERS.			FIGURES.
a —	*k* — · —	*u* · · —	1 · — — ·
b — · · ·	*l* — —	*v* · · · —	2 · · — · ·
c — · — ·	*m* — —	*w* · — —	3 · · · — ·
d — · ·	*n* — ·	*x* · — · ·	4 · · · · —
e ·	*o* · ·	*y* · — · ·	5 — — —
f · · — ·	*p* · — — — ·	*z* — — · ·	6 — · · · ·
g — — ·	*q* — — — ·	& · — · · ·	7 — — · ·
h · · · ·	*r* · — ·	, · — — —	8 — — · · ·
i · ·	*s* · · ·	? — · · — — ·	9 — — · —
j — · — —	*t* —	. · — · — · —	0 ———

(*a.*) To prevent confusion, a small space is left between successive letters, a longer one between words and a still longer one between sentences. We here give a short message written in Roman and in telegraphic characters;

H e w i l l c o m e a t ten .

---- - -—— -- —— —— ... -- —— - -—— -—— —-—- ---—-.

The ordinary telegraph operator does not punctuate his messages to any considerable extent. Telegraph operators soon become so

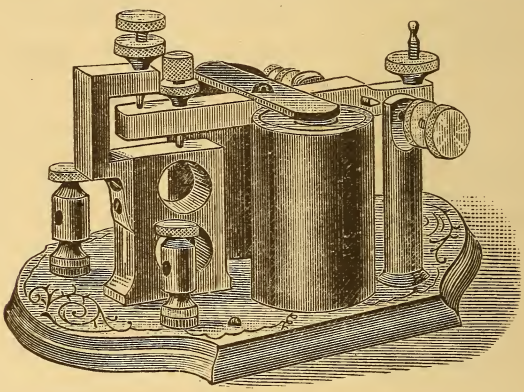


FIG. 229.

familiar with this alphabet that they understand a message from the mere clicks of the lever and do not use any recording apparatus. Such an operator is said to "read by sound"; his instrument is called a "sounder." Fig. 229 represents one. The sounder is placed on a local circuit and has a usual resistance of from three to five ohms.

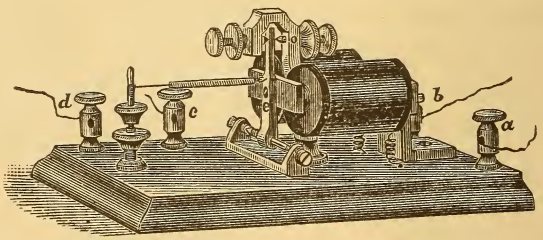


FIG. 230.

(*b.*) With a long main line, the resistance is so great that the current of the main battery is too feeble to operate the sounders with

sufficient force. This difficulty is met by introducing a "local battery" and a "relay" at each station on the line. The relay (Fig. 230) is a delicate electro-magnet, of which the terminals, *a* and *b*, are connected with the main line. This magnet operates an armature lever, *e*, the end of which strikes against a metal contact piece and thus closes the local circuit through the terminals, *c* and *d*. The resistance of relays vary from 50 to 500 ohms. The "Western Union" standard relay has a resistance of 150 ohms.

(*c.*) The arrangement of instruments is best studied at a telegraph station, one or more of which may be found at almost any town or railway station. The general features of the "plant" are represented by the diagram shown in Fig. 231. The pupil will probably find the key, sounder and relay on a table and the local battery, *b*, under the table. The keys being habitually closed, the current passes through all relays on the line, the current being continuous (§ 395) except when a message is being sent from some office. When an operator, in sending a message, opens his key, the breaking of the circuit stops the current, demagnetizes the relays and allows their springs to draw back the armature levers, *e*. This breaks each local circuit and demagnetizes each sounder, the spring of which raises its armature. Things are now as shown in the diagram, which also represents the condition of affairs at every other station on the line. When a message is sent from any station, each relay lever, *e*, acts as a key to its local circuit, it and the

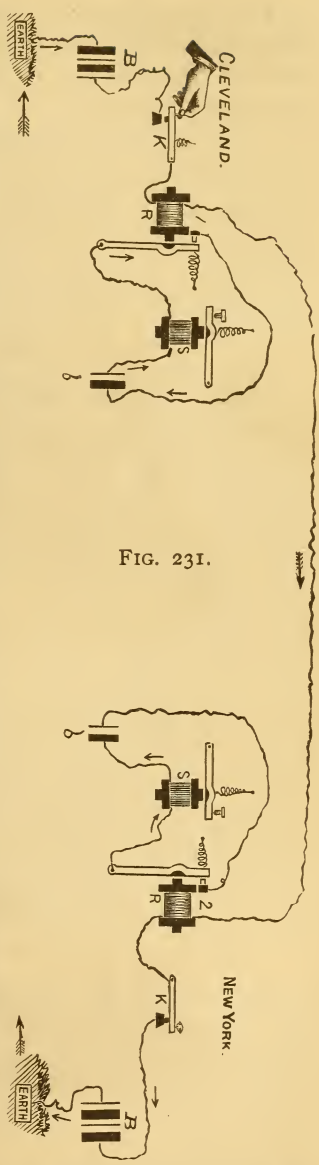


FIG. 231.

sounder lever vibrating in obedience to the motions of the key at the sending station. Of course, the sending operator can read his own message from his sounder. The message may also be read from any sounder on the line.

(*d.*) If the local circuit at New York (see Fig. 231) be lengthened so as to reach thence to Boston and the local battery, *b*, be increased to the dimensions of a main battery, *B*, (ground connections being made, of course), the relay at New York will transmit to Boston the message received from Cleveland. In such cases, the relay at New York becomes *a repeater*. Messages from New York to Chicago may thus be repeated at Meadville, Pa., without the intervention of any operator.

446. Duplex and Quadruplex Telegraphy.—The simple Morse system, just described, is very reliable, but a given wire can transmit only one message at a time. By what is known as the *duplex system*, a wire may be made to convey two messages, *one each way, at the same time*, without conflict. By what is known as the *quadruplex system*, a wire may be made to carry four messages, *two each way, at the same time.* Delany's *multiplex system* enables the sending of six messages in the same direction at one time. The student is referred to technical works on telegraphy for an explanation of these systems. A good Morse operator can send or receive thirty or forty words a minute; by the aid of a combination of recent inventions, fifteen hundred words have been transmitted over a single wire in one minute.

447. Electric Bells.—The construction of the trembler or electric bell will be clearly seen by an examination of Fig. 232. When the button at *P* (anywhere on the circuit) is pushed, two metal pieces are brought into contact and the circuit is thus completed. The spring carried by the armature of the magnet, *E*, makes contact

with the tip of the screw at *C*, except when it is drawn away by the attraction of the magnet.

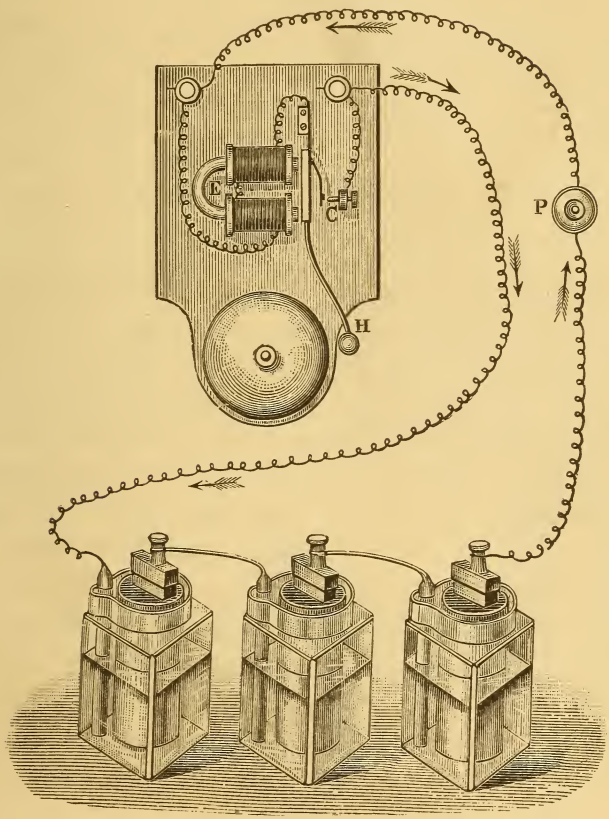


FIG. 232.

(*a.*) When the spring rests against the end of the screw at *C* (the circuit being closed at *P*), the cores of *E* are magnetized. They then draw the armature away from the end of the screw and break the circuit at *C*. *E*, being thus demagnetized, no longer attracts its armature, which is thrown back against the end of the screw by the elasticity of the spring that supports it. It is then again attracted and released, thus vibrating rapidly and striking a blow upon the bell at *H* at every vibration. (See § 459, *a.*)

448. Making Permanent Magnets.—A common way of magnetizing a steel bar is to draw one end of a strong magnet from one end of the bar to the other, repeating the operation several times, *always in the same direction.* A second method is to bring together the opposite poles of two magnets at the middle of the bar to be magnetized and simultaneously drawing them in opposite directions from the middle to the ends. A steel bar may be magnetized by striking it on end with a wooden mallet while it is held in the direction assumed by the dipping needle. If a bar of steel be heated to redness and cooled, either slowly or suddenly, while lying in the magnetic meridian, it acquires magnetic polarity. But better than any of these can give are the effects produced by electro-magnetism.

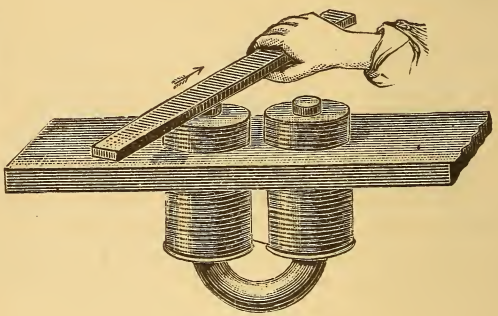


FIG. 233.

The bar may be permanently magnetized by drawing it, from its centre, in one direction over one pole of a powerful electro-magnet and then, from its centre, in the opposite direction over the other pole and repeating the process a few times (Fig. 233).

A bar of steel placed within a helix through which a

strong current is passing will be permanently magnetized. The bar should be passed into one end of the helix and removed from the other end.

(*a.*) A long, thin, steel magnet is more powerful in proportion to its weight than a thicker one is. Compound magnets are, therefore, made of thin pieces of steel, separately magnetized and then bound together in bundles. A horse-shoe magnet will lift a load three or four times as heavy as will a bar magnet of the same weight. The lifting power is increased if the area of contact between the poles and the armature is increased. The lifting power of a magnet is strengthened, in an unexplained way, by gradually increasing the load on its armature day by day until it bears a load which at the outset it could not have borne. If the load be so increased that the armature is torn off, the power of the magnet falls at once to its original value. The attraction between a powerful electro-magnet and its armature may amount to 200 lb. *per* square inch, or 14,000 *g. per sq. cm.* Small magnets lift a greater load in proportion to their own weight than large ones. A good steel horse-shoe magnet weighing one pound ought to lift twenty pounds' weight. A steel magnet loses part of its magnetism by being jarred or knocked about and all of it by being heated to redness.

449. Armatures. — Magnets left to themselves soon lose their magnetism. They should, therefore, be provided with armatures. *Armatures are pieces of soft iron placed in contact with opposite poles,* as shown in Fig. 234. The two poles of the magnet (or magnets, for two bar magnets may be thus protected) act inductively upon the armature and produce in it poles opposite in kind to those with which they come in contact. The poles of the armature in turn react upon the magnet and, by their power of attraction, aid in retaining the magnetism.

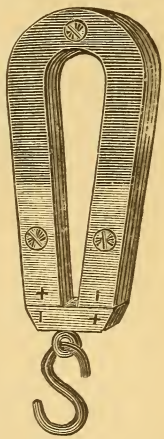


FIG. 234.

450. Magnetic Units.—All magnetic quantities, strength of poles, intensity of magnetization, etc., are expressed in terms of special units derived from the fundamental units of *length, mass* and *time, i.e.,* they are C. G. S. units.

(*a.*) *Unit Strength of Magnetic Pole.*—The unit magnetic pole is

one of such strength that it repels a similar pole of equal strength with a force of one dyne when it is placed at a distance of one centimeter from it.

(*b.*) *Magnetic Potential* being measured by *work* done in moving a unit magnetic pole against the magnetic forces, the unit of magnetic potential will be measured by the unit of work, the *erg*.

(*c.*) *Unit Difference of Magnetic Potential* exists between two points when it requires the expenditure of one *erg* of work to bring a — unit magnetic pole from one point to the other against the magnetic forces.

(*d.*) *Intensity of Magnetic Field* is measured by the *force* it exerts upon a unit magnetic pole; hence,

(*e.*) *Unit Intensity of Field* is that which acts on a unit — pole with a force of one dyne.

451. Electro-Magnetic Units.—The magnetic units just described give rise to a set of electrical units, in which *the strength of currents, etc., are expressed in magnetic measures.* (See § 320.)

(*a.*) *Unit Strength of Current.*—A current has unit strength when 1 *cm.* length of its circuit bent into an arc of 1 *cm.* radius (so as to be always 1 *cm.* away from the magnet-pole) exerts a force of one dyne on a unit magnet-pole placed at the centre.

(*b.*) *Unit of Quantity of Electricity* is that quantity which is conveyed by unit current in one second.

(*c.*) *Unit of Difference of Potential* (or of E. M. F.) is that which exists between two points when it requires the expenditure of one *erg* of work to bring a unit of + electricity from one point to the other against the electric force.

(*d.*) *Unit of Resistance.*—A conductor possesses unit resistance when unit difference of potential between its ends causes a current of unit strength to flow through it.

452. Practical Units.—As some of these "absolute" electro-magnetic units are too large for common, convenient use and others are too small, the practical units, the volt, the ohm, the ampere and the coulomb have been chosen and are generally used. These units have been already described, the value of each in absolute electro-magnetic units being given.

453. Molecular Changes in a Magnet.—When a steel or iron bar is strongly magnetized, it increases in length and diminishes in thickness. This effect is probably due to the magnetization of the individual molecules, which tend to set themselves parallel to the length of the bar. This supposition is confirmed by the observation that at the moment when a bar is magnetized or demagnetized, a faint metallic click is heard in the bar. When a tube containing water rendered muddy with finely divided magnetic oxide of iron is magnetized, the liquid becomes clearer in the direction of magnetization, the particles apparently setting themselves end to end and allowing more light to pass between them. A piece of iron, when powerfully magnetized and demagnetized in rapid succession, grows hot, as if the changes were accompanied by internal friction.

454. Theory of Magnetism.—These and other phenomena point to a theory of magnetism very different from the old notion of "magnetic fluids." It appears that every molecule of a magnet is itself a magnet and that the molar magnet becomes a magnet only by the molecular magnets being turned so as to point one way. This conclusion is supported by the observation that if a glass tube full of iron filings be magnetized, the filings may be seen to set themselves endwise and that, when thus once set, *they act as a magnet until they are shaken up.*

455. Relation of Magnetism to Energy.—A magnet is a reservoir of potential energy. This energy is due to the expenditure, at some time, of a definite amount of energy, of some kind. By virtue of its potential energy,

it can do a definite amount of work *and no more.* For instance, it may attract a certain amount of iron. When thus fully loaded, the magnet has done its full work and can do no more. *When the iron is torn from the magnet, more energy is expended and the magnet thus endowed again with potential energy. A magnet has not an inexhaustible supply of energy, as some have supposed.*

Exercises.

1. (*a.*) What is a magnetic pole? (*b.*) A magnetic equator? (*c.*) How does a magnet behave toward soft iron? (*d.*) How does soft iron behave toward a magnet?

2. (*a.*) State carefully the various effects that one magnet may exert upon a second magnet. (*b.*) Generalize these observed facts into a law.

3. On board an iron ship that is laying a submarine telegraph cable, there is a galvanometer used for testing the continuity of the cable. It is necessary to prevent the magnetized needle of the galvanometer from being affected by the magnetism of the ship. How can this be done?

4. (*a.*) Given a bar magnet, how would you determine the sign of either of its poles? (*b.*) What is a diamagnetic substance?

5. If a magnetic needle be freely suspended from its centre of gravity, what position will it assume?

6. (*a.*) Do you think that the earth is a magnet? (*b.*) Give a good reason for your answer. (*c.*) Do the magnetic and the geographical meridians ever coincide? (*d.*) Do they always coincide? (*e.*) If they do not coincide, what name would you give to their difference in direction?

7. (*a.*) Does the magnetic attraction of the earth upon a ship's compass *tend* to float the ship northward? (*b.*) If so, why? If not, why not?

8. (*a.*) State and illustrate the second law of motion. (*b.*) State and illustrate the law of universal gravitation. (*c.*) A body falls to the ground from rest in 11 seconds; what is the space passed over?

9. An electric bell in Cleveland, Ohio, is to be rung by a battery in New York City. Should the magnet coils of the bell be made of fine or coarse wire?

10. Would you use a long coil or a short coil galvanometer to measure the current used to ring the bell above mentioned?

11. Would it make any difference whether the galvanometer were put into the circuit at New York or at Cleveland if the line be thoroughly insulated?

12. With a local battery of 2 cells, each having an internal resistance of 2 ohms, what should be the resistance of the sounder?

13. The cells represented in Fig. 235 have each an E. M. F. of 2 volts and an internal resistance of 3 ohms. What is the resistance of the external circuit, *G*, if the battery is arranged in the best possible way? *Ans.* 2 ohms.

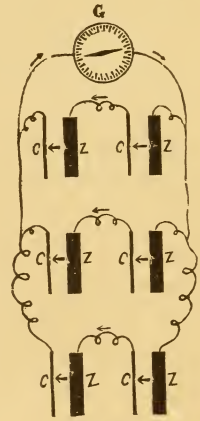


FIG. 235.

14. Why is it that when there is little other resistance in the circuit, a stout wire with few turns will make a stronger electro-magnet than a very fine wire with many more turns?

15. A battery of 5 Leclanché cells was connected in simple circuit with a galvanometer and a box of resistance coils. A deflection of 40° having been obtained by adjustment of the resistances, it was found that the introduction of 150 additional ohms of resistance brought down the deflection to 29°. A battery of ten Daniell's cells was then substituted in the circuit and adjusted until the resistance was 40° as before. But this time it was found that 216 ohms had to be added before the deflection was brought down to 29°. Taking the E. M. F. of a single Daniell's cell as 1.079 volt, calculate that of a single Leclanché cell. *Ans.* 1.499 volt.

16. An electric bell has a resistance of 0.5 ohm. It requires a current of 20 milliamperes to ring it. It is on a line of 1 mile of No. 20 copper wire (see Appendix I). Ignoring the internal resistance of the battery, find how many Leclanché cells (*E. M. F.* = 1.5 volts) will be required.

17. We have to send a current through a telegraph line, 100 miles long, the resistance of which is 13 ohms *per* mile. The battery is composed of Daniell cells, each having an E. M. F. of 1.079 volts and an internal resistance of 2 ohms. The telegraphic instrument offers a resistance of 130 ohms and requires a current of 10 milliamperes to work it. Will one cell of battery answer our purpose? Why?

18. Under what circumstances will a magnet repel an unmagnetized piece of iron?

19. Give two or three differences between electric attractions and repulsions and magnetic attractions and repulsions.

20. A zinc and a copper plate are respectively united by copper wires to the terminals of a galvanometer. They are dipped, side by side, into a glass containing dilute sulphuric acid. The galvanometer needle, at first, shows a deflection of 28°, but five minutes later the deflection has fallen to 11°. How do you account for this falling off?

21. A wire, the resistance of which was to be determined, was placed in a Wheatstone's bridge, in which resistances of 10 and 100 ohms respectively were used as the fixed resistances. Its resistance was balanced when the adjustable coils were arranged to throw 281 ohms into circuit. What was its resistance? (See Appendix M, [*e*.].)

Ans. 25.1 ohms.

22. Relays are wound with long, fine wire and sounders with short, stout wire. Why is there this difference?

Recapitulation.—To be amplified by the pupil for review.

- MAGNETISM.
  - **MAGNETS.**
    - NATURAL.
    - ARTIFICIAL...
      - PERMANENT.....
        - *Forms.*
        - *How Made.*
      - TEMPORARY OR ELECTRO-MAGNETS.
        - *Definition.*
        - *Advantages.*
        - *Forms.*
        - *Residual Magnetism.*
        - *Telegraph.*
        - *Electric Bells.*
    - MOLECULAR..
      - MAGNETS.
      - CHANGES.
    - POLES.
    - CHARACTERISTICS.
    - LAWS.
    - RELATION TO
      - MAGNETIC .....
      - DIAMAGNETIC. ...
      - *Substances.*
  - **RETENTIVITY.**
  - **THEORY.**
  - **MAGNETIZATION.**
    - BY CONTACT.
    - MODES OF.
    - BY INDUCTION.
      - MAGNETIC FIELD.
      - LINES OF FORCE.
      - PRECEDES ATTRACTION.
      - MAGNETIC SCREENS.
  - **TERRESTRIAL.....**
    - POLES.
    - MAGNETIC NEEDLES.
      - COMPASS.
      - DIPPING.
      - ASTATIC.
    - DIP.
    - DECLINATION.
  - **MAGNETIC AND ELECTRO-MAGNETIC UNITS.**
  - **RELATION TO ENERGY.**

SECTION V.

INDUCED ELECTRICITY.

456. Induced Currents. — From our study of frictional electricity and magnetism, we are familiar with the term *induction*, by which we understand the influence that an electrified body exerts upon a neighboring unelectrified body or that a magnetized body exerts upon a neighboring magnetic but unmagnetized body. In 1831, Faraday discovered an analogous class of phenomena which we are now about to consider. *An induced current is a current produced in a conductor by the influence of a neighboring current or magnet.* A current used to produce such an effect is called an inducing current.

457. Inductive Effect of Closing or Breaking a Circuit.—In Fig. 236, *B* represents a double coil made as follows: On a hollow cylinder of wood or card-board are wound several layers of stout, insulated, copper wire. The two ends of this wire, which constitutes the *primary coil*, are seen dipping into the cups, *g g'*. Upon this coil and carefully insulated from it, is wound a much greater length of finer, insulated copper wire. The two ends of this wire, which constitutes the *secondary coil*, are seen connecting with a delicate, long coil galvanometer, *G*.

Remember that there is no electrical connection between the two coils. Wires from the poles of a voltaic cell, *P*, dip into mercury in the cups *g g'*, thus closing a circuit through the primary coil of *B*. While this circuit is closed, the galvanometer needle is at rest, showing that no current is passing through the secondary coil. By lifting one of the wires from its cup, the inducing current is interrupted. At this instant, the galvanometer needle

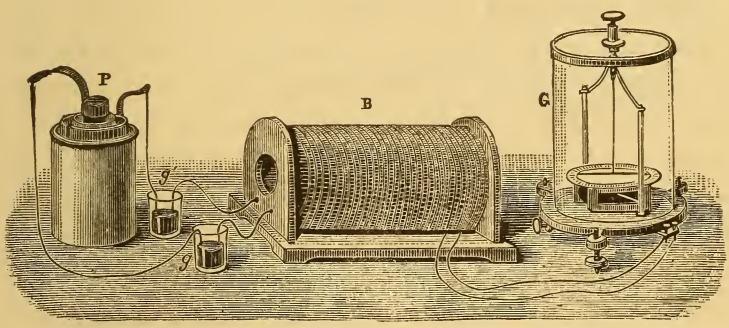


FIG. 236.

is deflected, as by a sudden impulse that immediately passes away. This movement of the galvanometer needle shows the existence of a momentary, induced current in the secondary coil. The direction in which the needle turns, shows that the secondary current is direct, *i. e.*, that it has the same direction as the inducing current. If the wire just removed from the cup be replaced and the inducing current thus re-established, the galvanometer needle will be momentarily turned in the direction opposite to that in which it was previously turned. *When a current begins to flow through the primary coil, it induces a current in the secondary coil. When*

it ceases to flow through the primary coil, a current flowing in the opposite direction is induced in the secondary coil. Both induced currents are merely momentary in duration.

458. The Extra Current.—When a circuit is made or broken, each convolution of a coil placed in the circuit acts inductively upon the other convolutions of the coil as if they were portions of two unconnected circuits. *This action is called the induction of a current upon itself; the current thus produced is called the extra current.*

(*a.*) When the circuit is made, the extra current is inverse or opposite in direction to the primary current and acts against it. The extra current at the breaking of the circuit is direct and *adds its effect to that of the primary current.* Hence, a spark is more often seen on breaking than on making contact. Increasing the number of coils or convolutions in the circuit will increase the brilliancy of the spark. If the coil has an iron core (electro-magnet) the effect is especially marked.

459. Ruhmkorff's Coil.—The induction coil, often called, from the name of its inventor, *Ruhmkorff's coil, is a contrivance for producing induced currents in a secondary coil by closing and opening, in rapid succession, the circuit of a current in the primary coil.* The essential parts are described in § 457. In the complete instrument, the axis of the coils is a bundle of soft iron wires. These wires usually terminate in two small plates of soft iron which thus form the ends of the wire bundle. Around this bundle, is wound the primary coil of stout, insulated, copper wire. Upon the primary coil, but carefully insulated from it, is wound

the secondary coil which is made of a great many turns of fine, silk covered, copper wire.

(*a.*) The wire bundle (*M*, Fig 238) becomes magnetized by the action of the battery current in the primary coil and then adds its inductive effect upon the secondary coil to the effect of the primary itself. The primary circuit is rapidly broken and closed by an automatic interrupter or contact breaker, represented at the left hand of the coil, Fig. 237, and at the right hand of the diagram in Fig. 238. One of the posts there seen carries an elastic, metallic, vibrating plate with an iron hammer, *b*, at its end. This hammer vibrates back and forth between the end of the iron core of the coils and the end of the metal adjusting screw, *d*, which is carried by the other post seen in the figure. These posts are in the primary circuit. When the hammer rests against the end of the adjusting screw, the circuit is closed and the iron core is magnetized. As soon as the core is magnetized, it attracts the hammer, thus drawing it away from the end of the screw and breaking the circuit. As soon as the circuit is broken, the bar is demagnetized and the plate, by virtue of its elasticity, throws the hammer back against the screw, closing the circuit and again magnetizing the core. The plate is thus made to vibrate with great rapidity, each oscillation making or breaking the primary circuit and creating a series of induced currents in the secondary coil.

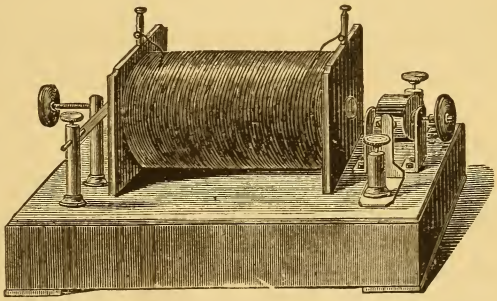


FIG. 237.

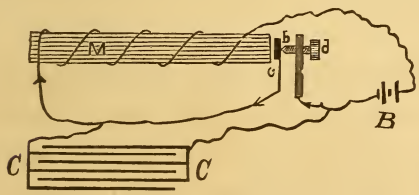


FIG. 238.

(*b.*) The *condenser* (*C C*, Fig. 238), which is generally placed in the pedestal or base of the coil, consists of a number of sheets of tinfoil insulated from each other by thin sheets of varnished paper

or oiled silk. Alternate layers of the tinfoil are connected, *i. e.*, the first, third, fifth, seventh, *etc.*, layers are connected, as also are the second, fourth, sixth, eighth, *etc.*, thus forming two separate, insulated series. One series (*e. g.*, the odd numbered sheets) is connected with one of the posts of the contact breaker; the other series, with the other post. Thus, the plates of the condenser do not form a part of the primary circuit but are, as it were, lateral expansions of that circuit, one on each side of the contact breaker. The effect of the condenser is to lessen the spark when the primary circuit is made or broken and to increase the force of the discharge of the secondary coil.

(*c.*) For an ordinary Ruhmkorff's coil, one to three Bunsen or potassim di-chromate elements will suffice.

(*d.*) Most induction coils are provided with a *commutator*, for the purpose of changing the direction of the current through the primary coil and, consequently, the direction of the currents induced in the secondary coil. One form of the commutator is shown at the right hand end of Fig. 237. It is not an essential part of the instrument.

Experiment 104.—Let the members of the class join bare hands. Let the pupil at one end of the line place a finger on one of the binding posts or electrodes of the secondary coil of *a small* induction coil. Then let the pupil at the other end of the line, momentarily touch the other electrode. Each person in the line will feel a "shock." The experiment should not be tried with a powerful coil, as the spasmodic, muscular contractions thus produced are sometimes painful and permanently injurious.

460. Spark from the Induction Coil.—If the ends of the secondary coil be connected, opposite currents alternately traverse the connecting wire. When the ends are disconnected, the inverse current cannot overcome the resistance of the intervening air because of its low electromotive power (§ 458, *a*). *The direct current, produced by breaking the primary circuit, is alone able to force its way in the form of a spark.* The sparks vary with the power of the instrument.

(*a.*) Mr. Spottiswoode, of London, has made an induction coil, the secondary coil of which contains 280 miles of wire wound in 340,000 turns. This magnificent instrument has a resistance of more than

100,000 ohms, and, when worked with a battery of 30 Grove cells, yields a spark 42½ inches long,—a result greater than that obtainable from any electric machine. The induction coil may be used to produce any of the effects of frictional electricity, it being at the same time nearly free from the limitations that atmospheric moisture places upon ordinary electric machines.

(*b.*) For many instructive and beautiful experiments with this instrument and other information relating thereto, see the little book, "Induction coils:—How made and how used," published by D. Van Nostrand, New York; Price, 50 cents.

461. Currents Induced by Change of Distance.—If the primary coil be made movable, as shown in Fig. 239, and, with a current passing through it, be suddenly placed within the secondary coil, the galvanometer will show that an inverse current is induced in the outer coil. When the needle has come to rest, let the primary coil be removed and the galvanometer will show that a direct current is induced. From this we see that *when the primary coil, bearing a current, is brought near or thrust into the secondary coil, an inverse current is induced in the latter; that when the coils are separated, a direct current is induced in the secondary coil; that the induced currents flow while a change of distance is varying the inductive effect of the primary current.* Removing the primary coil to an infinite distance is equivalent to breaking its circuit, as in § 457.

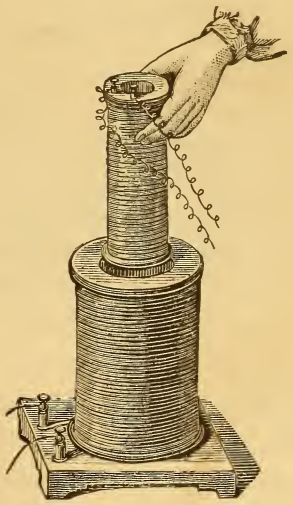


FIG. 239.

462. Magneto-Electric Currents. — We have already noticed that there is an intimate relation between electric and magnetic action. We have seen that an electric current may develop magnetism. Faraday found that electricity may be developed by magnets; the results of this discovery have already become of incalculable commercial importance. If, instead of the primary coil bearing the

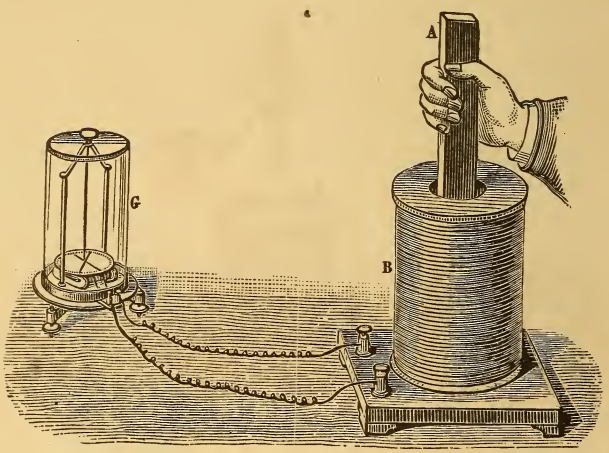


FIG. 240.

inducing current, a bar magnet be used, as shown in Fig. 240, the effects produced will be like those stated in the last paragraph. *When the magnet is thrust into the interior of the coil, an induced current will flow while the motion of the magnet continues. When the magnet becomes stationary, the current ceases to flow and the needle of the galvanometer gradually comes to rest. When the magnet is withdrawn, an induced current flows in the opposite direction.* Of course, it makes no difference whether the magnet be

moved toward the coil or the coil be moved toward the magnet. The more rapid the motion, the greater will be the electromotive force of the induced currents.

463. The Inductive Action of a Temporary Magnet.—If within the coil, a soft iron bar (or still better, a bundle of straight, soft, iron wires) be placed, as shown in Fig. 241, the induced current may be more

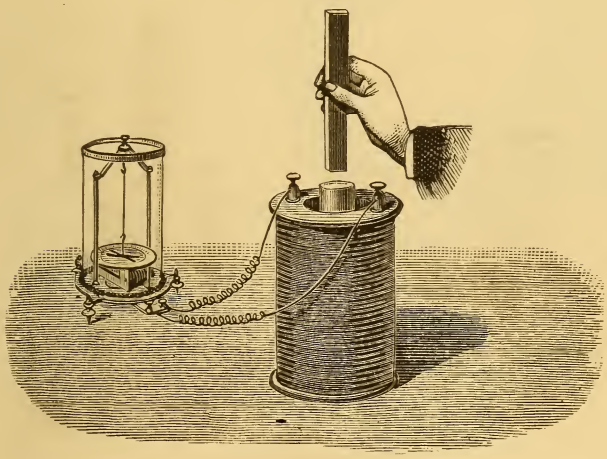


FIG. 241.

effectively produced by bringing one end of a permanent magnet near the end of the soft iron. In this case, the induced currents are due to the varying magnetism of the soft iron, this magnetism being due, in turn, to the inductive influence of the permanent magnet. Thus we see that *when the intensity of the magnetism of a bar of iron or steel is increased or diminished, currents are induced in the neighboring coil.* Similar effects may be produced by moving one pole of the magnet across the face of the coil from end to end.

464. The Wheel Armature.—Imagine the soft iron bar in the helix of Fig. 241 to be grooved and several times as long as the helix through which it passes. Imagine the ends of this bar to be brought together so as to form a complete iron ring carrying one helix. If the number of helices upon the ring be increased to twelve we shall have the wheel armature, shown, in an unfinished condition, in Fig. 242. If the pole of a magnet be passed around the face of this wheel, it will pass twelve coils of wire and induce a current of electricity as it approaches each coil and an opposite current as it leaves each coil, thus inducing twenty-four currents for each revolution. Of course, it makes no difference whether the magnet be permanent or temporary, *whether the pole of the magnet moves by the coil or the coil passes by the pole of the magnet.* Then, if the magnet be fixed and the wheel turn upon its axis in such a way as to carry its coils across the end of the magnet, we shall be inducing twenty-four currents of electricity for each revolution of the wheel. This is what happens in the operation of a dynamo-electric machine. *When a closed circuit conductor moves in a magnetic field so as to cut across the lines of magnetic force* (§ 433), *an induced current of electricity flows through the conductor in one direction while the*

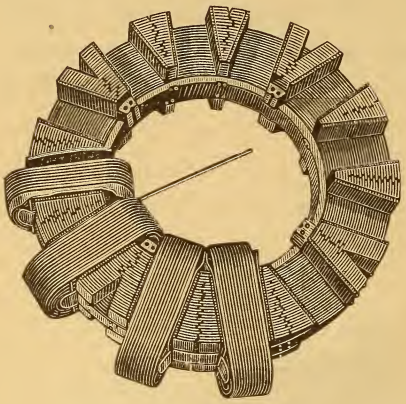


FIG. 242.

conductor is approaching the point of greatest magnetic intensity and in the opposite direction while the conductor is moving away from such point of maximum intensity. The varying magnetic intensity of the iron core of each moving coil increases this effect as explained in § 463. Of course, the number of coils on the armature may be more or less than twelve, or the armature may be of a form almost wholly different from that just described, but, in every case, the principle of its action is as above stated. The dynamo represented in Fig. 243 has only eight armature helices and diametrically opposite coils are joined so as to form four pairs.

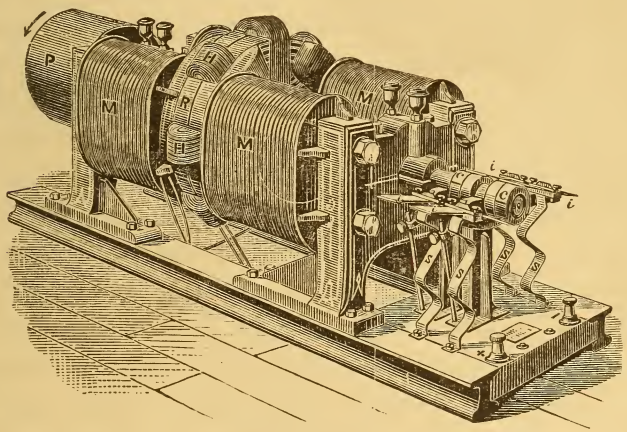


FIG. 243.

465. Dynamo-Electric Machines. — In the Brush dynamo-electric machine, represented in Fig. 243, a shaft runs through the machine from end to end, carrying a pulley, *P*, at one end, a commutator, *c*, at the other, and a wheel armature, *R*, at the middle. The armature, *R*, carries eight or more helices of insulated wire, *H H*.

As the shaft is turned by the belt acting upon *P*, *R* and *c* are turned with it. As *R* turns around, it carries the eight coils, *H H*, rapidly across the poles of the four powerful field magnets, *M M*.

As each coil passes each pole, it necessarily traverses the magnetic field and cuts across the lines of magnetic force; consequently, currents are induced in the coil. These currents are carried on insulated wires to the commutator rings, *c c*, where they are united in such a way as all to flow in the same direction, forming a continuous current. The electricity is taken from the revolving commutator, *c c*, by the four or more fixed, copper plates, *i i*, technically called "brushes," then carried down the flexible copper strips, *s s*, then passed through the insulated wire of the electro-magnets, *M M*, and, finally, to the + binding post. Thence the current passes by a wire to the external circuit, *e. g.*, to an arc lamp (Fig. 246) and from this to a second lamp, and so on through all of the lamps of the circuit and from the last lamp back to the — binding post of the dynamo-electric machine, thus making the circuit complete. Sixty or more arc lamps in series may be worked by one of these machines. No part of the circuit of a dynamo should have an earth connection. The complete circuit (except through the lamp carbons) should be of carefully insulated wire.

Dynamo-electric machines are being rapidly introduced for purposes of electric lighting, electro-plating, motive power, telegraphy, *etc.* They are made in various forms, but the principle underlying the action of them all is the same as that stated in the last paragraph. After mastering the action of one dynamo-electric machine the pupil

will have little trouble in understanding the action of any other that he may have a chance to examine. Dynamo-electric machines are often called "dynamos." A small, hand power dynamo, suitable for school use, may be had for $30 or more.

(*a.*) In cases where a high E. M. F. is needed (as in arc electric lighting), the armature helices are wound with many turns of wire which gives a high internal resistance. Compare § 399. When a smaller E. M. F. is wanted (as in direct, incandescence electric lighting or in electro-plating), fewer turns of wire of greater diameter are used. This reduces the internal resistance of the dynamo. Compare § 400. The E. M. F. will vary with the strength of the magnetic field and the speed at which the armature is revolved. Thus, a given dynamo may be run slowly for a few lamps and at a higher speed for a greater number of lamps. In practice, however, special automatic devices are generally provided for adapting the E. M. F. to the varying resistances of the external circuit without changing the speed of the dynamo.

(*b.*) If permanent magnets are used instead of electro-magnets, the machine is called a *magneto-electric* instead of a dynamo-electric machine. Small magnetos (armatures wound with long, thin wires) are much used for electro-medical purposes. The patient holds two metallic handles connected with the terminals of the instrument and receives a rapid succession of shocks when the armature is turned.

(*c.*) If, instead of expending mechanical energy to turn the shaft of the dynamo and thus produce an electric current, we pass a strong current of electricity through the dynamo, the shaft of the dynamo will be turned in the opposite direction and may be made to drive ordinary machinery as an *electric motor*. In the former case, we convert mechanical energy into electric energy ; in the latter case, we convert electric energy into mechanical energy (§ 473).

466. Incandescence Electric Lamps.—When a conductor of high resistance is heated to incandescence by the passage of a current, we have an illustration of the fundamental principle of incandescence electric lighting. To prevent the fusion of the conductor, a carbon

filament, about the size of a horse-hair, is used—carbon never having been melted. To prevent the combustion of the carbon filament, it is enclosed in a glass globe containing either a high vacuum or only some inert gas, incapable of acting chemically upon the carbon at even the high temperature to which it is to be subjected. The ends of the carbon are connected with platinum wires that are fused into and passed through the glass.

THE SWAN ELECTRIC LAMP.

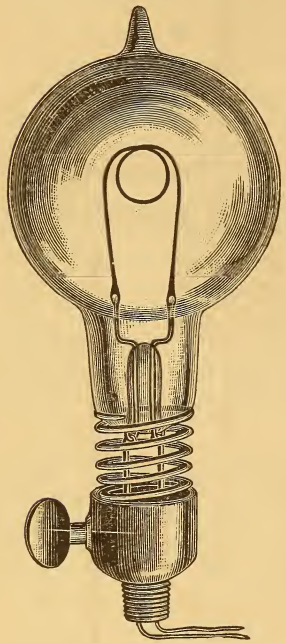


FIG. 244.

(*a.*) The filament is carbonized in different ways and given different shapes by different inventors. The Edison carbon is made of bamboo fibre and is in the shape of an ordinary hair pin. The Swan carbon is made of parchmentized cotton thread. Fig. 244 represents the Swan incandescence lamp and is half the actual size of the standard sixteen candle power lamp. Incandescence lamps are generally operated abreast, as shown in Fig. 245, being placed, as it were, in little bridges of wire connecting the two conductor "mains." Thus, *the resistance of the circuit is reduced by the successive addition of lamps.*

(*b.*) The resistance of carbon is lowered by heating the conductor. The "hot" resistance of an incandescence lamp is about $\frac{2}{3}$ its "cold" resistance.

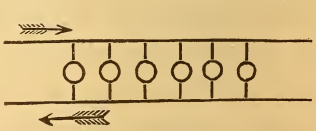


FIG. 245.

467. The Voltaic Arc.— The most brilliant luminous effect of current electricity is the arc of an electric lamp. This lamp consists essentially of two pointed bars of hard carbon, generally copper coated

(Experiment 78), placed end to end in the circuit of a powerful current. If the ends of the carbons be separated a short distance while the current is passing, the carbon points become intensely heated and the current will not be interrupted thereby. *When the carbons are thus separated, their tips glow with a brilliancy which exceeds that of any other light under human control, while the temperature of the intervening arc is unequalled by any other source of artificial heat.*

THE BRUSH ELECTRIC LAMP.

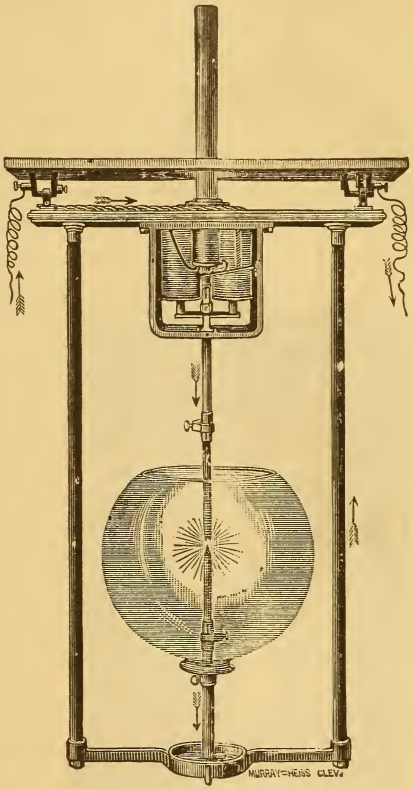


FIG. 246.

The mechanism shown in the upper part of Fig. 246, is for the purpose of automatically separating the carbons and "feeding" them together as they are burned away at their tips and for the purpose of cutting the lamp out of the circuit in case of any irregularity or accident. Such lamps of from one to two thousand candle power and requiring an expenditure, at the dynamo, of about one-horse power *per* lamp are

now quite common. Lamps of a hundred thousand candle power have been made. The current may be furnished by a battery of forty or more Grove's cells but, for economical reasons, it is almost universally supplied by a dynamo-electric machine.

(*a.*) It is necessary to bring the carbons into contact to start the light. The tips of the carbons become intensely heated on account of their small area of contact and the consequent high resistance at that point. The carbon (and its usual copper coating) begins to volatilize. When the carbons are separated, the current is kept up by this intervening layer of vapor and the accompanying disintegrated matter, which act as a conductor. Arc lamps are generally operated in series, so that the current passes in succession through all the lamps on the circuit. *The resistance of the circuit is thus increased by the successive addition of lamps.*

FIG. 247.

(*b.*) The constitution of the voltaic arc may be studied by projecting its image on a screen with a lens. Three parts will be noticed:

1. The dazzling white, concave extremity of the positive carbon.
2. The less brilliant and more pointed tip of the negative carbon.
3. The globe shaped and beautifully colored aureole surrounding the whole.

(*c.*) There is a transfer of matter across the arc in the direction of the current, the positive carbon wasting away more than twice as rapidly as the negative. Most of the light of the lamp is radiated from the crater at the end of the positive carbon. If the arc be too short, many of these rays will be intercepted by the negative (generally the lower) carbon, thus lessening the efficiency of the

lamp. If the arc become too long, it will "flame" and much of the light thus be lost. If the electrodes be horizontal, the arc will be curved upward by ascending air currents. Arc lamps are now largely used for lighting streets, factories, stores, etc., many thousands having been sold in every quarter of the globe (§ 000).

468. The Telephonic Current.—An electric current may be induced in a coil of insulated wire surrounding a bar magnet by the approach and withdrawal of a disc of soft iron. The disc, *a* (Fig. 248), is magnetized by the inductive influence of the magnet, *m*, (§ 435). The disc, thus magnetized, reacts upon the magnet, *m*, and changes the distribution of magnetism therein. By varying the distance between *a* and *m*, the successive changes in the distribution of the magnetism of *m* induce to-and-fro currents in the surrounding coil (§ 463). When *a* approaches *m*, a current flows in one direction; when it recedes, the current flows in the opposite direction.

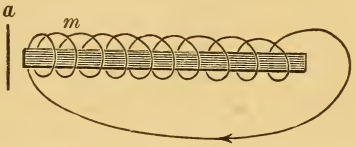


FIG. 248.

469. The Telephonic Circuit.—If the wire surrounding the magnet mentioned in the last paragraph be continued to a distance and then wound around a second bar magnet, as shown in Fig. 249, the currents induced at *M* would affect the magnetism of the bar at *M'* or the intensity of its attraction for the neighboring disc, *a'*. A vibratory motion in the disc, *a*, would induce electric currents at *M*; these currents, when transmitted to *M'*, perhaps several miles distant, would affect the magnetism of the bar there and tend to produce exactly similar vibra-

tions in a'. "It is as if the close approach and quick oscillation of the piece of soft iron fretted or tantalized

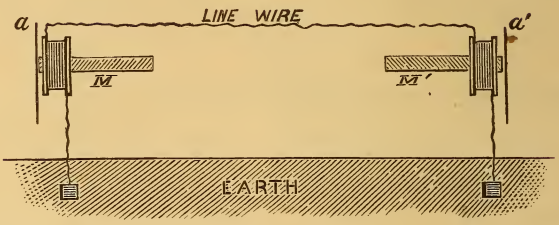


FIG. 249.

the magnet and sent a series of electrical shudders through the iron nerve." When the current generated at M flows in such a direction as to reinforce the magnet at M', the latter attracts a' more strongly than it did before. When the current flows in the opposite direction, it weakens the magnetism of M', which then attracts a' less. The disc, therefore, flies back. Thus, the vibrations of a' are like those of a.

(a.) We have here the principle of the telephone, so far as electric action is involved. Further consideration of this instrument must be deferred until we have learned more concerning sound. (See § 504.)

Exercises.

1. A dynamo is feeding 16 arc lamps, the average resistance of each of which is 4.56 ohms. The internal resistance of the dynamo (*i.e.*, of the wire conductors of the armature and field magnets) is 10.55 ohms. What current does the dynamo yield?

Ans. 10.04 amperes.

2. If a wire about 18 inches long be attached to one electrode of a potassium dichromate cell and the other electrode momentarily touched with the other end of the wire, a minute spark may be noticed at the instant of breaking the circuit. If the wire be bent into a scalariform or ladder like shape and the experiment repeated, the spark will be greater than before. If the form of the external circuit be again changed by winding the wire into a spiral (as shown in Fig. 250), the spark will be still greater. Explain the repeated increase in the spark.

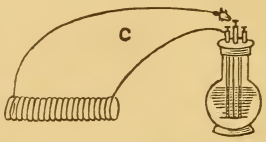


Fig. 250.

3. A dynamo is run at 450 revolutions, developing a current of 9.925 amperes. This current deflects the needle of a tangent galvanometer, 60°. (See Appendix L.) When the speed of the dynamo is sufficiently increased, the galvanometer shows a deflection of 74°. What is the current developed at the higher speed?

Ans. 20 amperes.

4. The current running through the carbon filament of an incandescence lamp was found to be 1 ampere. The difference of potential between the two terminals of the lamp was found to be 30 volts. What was the resistance of the lamp?

5. A yard of silver wire weighs 7.2 grains and has a resistance of 0.3 ohm. What is the resistance of a foot of silver wire that weighs one grain? *Ans.* 0.24 ohm.

6. If a pure copper wire has a weight of one grain and a resistance of 0.2106 ohms per foot and a commercial copper wire has a weight of 164 grains and a resistance of 0.547 ohms per 20 ft., what is the percentage conductivity of the latter as compared with pure copper?

Ans. 93.9 per cent.

7. I want to place, in series, 10 incandescence lamps, each of 25 ohms resistance; the line wire is to be 200 feet long and must have not more than 2 per cent. of the resistance of the lamps. Determine from the table in Appendix I what size of wire (American gauge) should be used. *Ans.* No. 24.

8. I want to place the same lamps abreast. The line wire is to be 200 feet long and have a resistance of not more than 2 per cent. that of the lamps. Determine from the table what size wire should be used. *Ans.* No. 4 (B. & S.)

9. What length of No. 0000 pure copper wire (B. & S.) will have a resistance of 1 ohm? (See Appendix I.) *Ans.* 19607.84 ft.

10. A dynamo has an E. M. F. of 206 volts and an internal (or interpolar) resistance of 1.6 ohms. Find the current strength when the external resistance is 25.4 ohms. *Ans.* 7.6 amperes.

11. A dynamo has an internal resistance of 2.8 ohms. The line wire has a resistance of 1.1 ohms and joins the dynamo to 3 arc lamps in series, each lamp having a resistance 3.12 ohms. Under such conditions, the dynamo develops a current of 14.8 amperes. What is the E. M. F.? *Ans.* 196.25 volts.

12. A dynamo, run at a certain speed, gives an E. M. F. of 200 volts. It has an internal resistance of 0.5 ohm. In the external circuit are 3 arc lamps in series, each having a resistance of 2.5 ohms. The line wire has a resistance of 0.5 ohm. I want a current of just 25 amperes. Must I increase or lessen the speed of dynamo?

13. With an external resistance of 1.14 ohms, a dynamo develops a current of 81.58 volts and 29.67 amperes. What is the internal resistance of the dynamo? *Ans.* 1.61 ohms.

14. Upon trial, it was found that a dynamo that was known to have an internal resistance of 4.58 ohms developed a current of 157.5 volts and 17.5 amperes. What was the resistance of the external circuit? *Ans.* 4.42 ohms.

15. Three incandescence lamps having a resistance of 39.3 ohms each (when hot) were placed in series. The total resistance of the circuit outside of the lamps was 11.2 ohms. The current measured 1.2 amperes. What was the E. M. F.? *Ans.* 154.92 volts.

16. The same lamps were placed in multiple arc with another dynamo. The line wire was adjusted so that its resistance with the internal resistance of the machine was 11.2 ohms as before. The current was 1.2 amperes. What was the E. M. F.?

Ans. 29.16 volts.

17. A dynamo supplies current for two incandescence lamps in series, each having a hot resistance of 97 ohms. The other resistances of the circuit amounted to 12 ohms. The current in the first lamp was 1 ampere. What was the current carried by the carbon filament of the second lamp? What was the E. M. F.?

18. The resistance of the normal arc of an electric lamp is 3.8 ohms. The current strength is 10 amperes. What is the difference of potential between the carbon tips. *Ans.* 38 volts.

19. The resistance of the arc lamp above mentioned, when the carbons are held together, is 0.62 ohm. When it is burning with normal arc and a 10 ampere current, what is the difference of potential between the terminals of the lamp? *Ans.* 44.2 volts.

HONORARY PROBLEMS.

20. Four arc lamps, with a resistance of 6 ohms each, are joined in series, 150 feet apart. The first lamp is 1,500 feet and the last is 1,350 feet from the dynamo. The line wire has a conductivity of 96 per cent. that of pure copper. Its resistance must not exceed 8 per cent. of that of the lamps. The resistance of a foot of pure copper wire 1 mil in diameter being 9.94 ohms, what must be the diameter of the line wire? *Ans.* 133 mils or 0.133 inch.

Use No. 10 wire, B. W. G. (App. I).

21. Twenty-five similar voltaic cells having an internal resistance of 15 ohms each were joined in series, by short and stout copper wires to a 70 ohms incandescence lamp and produced a current of 0.112 ampere. What would be the strength of the current sent by a series of 30 such cells through a series of 2 lamps, each of 30 ohms resistance? *Ans.* 0.118 ampere.

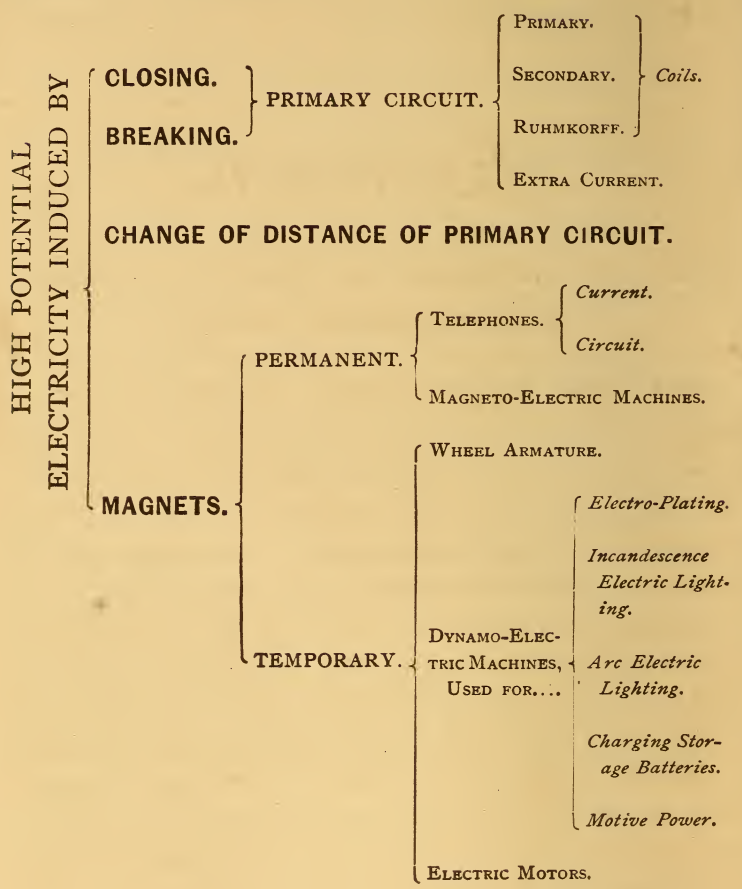
22. What would have been the strength of current through the two lamps if the area of each of the battery plates had been doubled, all things else remaining the same? *Ans.* 0.215 ampere.

23. I join 50 arc lamps in series. Each lamp has a resistance of 4.5 ohms. The line wire connecting them with the dynamo is $3\frac{1}{2}$ miles long and its conductivity is 90 per cent. that of pure copper. One tenth of the total energy of the external circuit is lost in heating this line wire. What is its diameter, it being assumed that 1 foot of pure copper wire. 1 mil in diameter has a resistance of 9.94 ohms.

Ans. 90.3 mils.

Use No. 11 wire (B. & S.)

Recapitulation.—To be amplified by the pupil for review.



SECTION VI.

ELECTRIC CURRENTS AS RELATED TO HEAT AND MECHANICAL WORK.

470. The Convertibility of Electric Energy.—Whenever an electric current does work of any kind, it does it at the expense of a part of its own energy. Anything that increases the resistance of a circuit, decreases the strength of the current (§ 386). But such a diminution may be caused by a counter electromotive force set up somewhere in the circuit. The E. M. F. of polarization is an example of the truth under consideration. Whenever a current is used to drive an electric motor, the action of the motor generates a back current that diminishes the current of the battery or dynamo. *All of the current that is not expended in some such way, in external work, is dissipated as heat.* The dissipation may be in the battery (or dynamo), in the external circuit or in both. The heat will appear wherever there is resistance. If the poles of a battery or dynamo be short circuited, most of the heat will be developed in the battery or dynamo. If the external circuit be a thin wire of high resistance, it will grow hot while the generator will remain comparatively cool.

471. Joule's Law.—The quantity of heat developed in a conductor by the passage of an electric current is proportional:—

(1.) To the resistance of the conductor.

(2.) To the square of the strength of the current.

(3.) To the time the current is flowing.

A current of one ampere flowing through a resistance of one ohm, develops therein, *per* second, a quantity of heat which (or its mechanical equivalent) is called a *joule*. It is equal to 0.7373 of a foot-pound or to 0.24 of a lesser calorie (§ 579). A lesser calorie is, therefore, equal to 4.17 joules.

These facts are concisely stated by the following equation, known as Joule's Law:—

$$H = C^2 Rt \times 0.24,$$

in which H represents the number of lesser calories; C, the number of amperes; R, the number of ohms and t, the number of seconds. In other words, *a current of one ampere flowing through a resistance of one ohm develops therein 0.24 of a lesser calorie per second.*

$$\text{Foot-pounds} = C^2 Rt \times 0.737335.$$

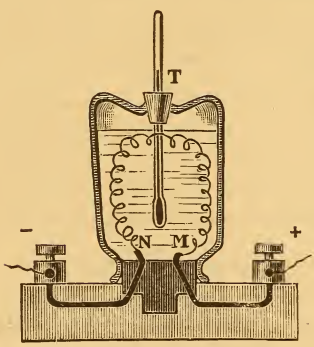


FIG. 251.

(*a.*) In investigating this subject, Joule used instruments on the principle indicated in Fig. 251, in which a thin wire joined to two stout conductors is enclosed within a glass vessel containing alcohol, into which a thermometer dips. The resistance of the wire being known, its relation to the other resistances may be calculated.

Experiment 105.—Send the current from a few cells through a chain made of alternate links of silver and platinum wires. The platinum links grow red-hot while

the silver links remain comparatively cool. The explanation is that the specific resistance (Appendix K, [2]) of platinum is about six times that of silver and that its specific heat is about twice as great; hence the rise of temperature in wires of equal thickness traversed by the same current is about twelve times as great for platinum as for silver.

472. Heating Wires by the Current. — The resistance of metals increases with the temperature. Consequently, a thin wire heated by the current will resist more and more and grow hotter and hotter until it loses heat by conduction and radiation into the surrounding air as rapidly as heat is supplied by the current. *Thin wires heat much more rapidly than thick. The rise of temperature in different parts of a wire of uniform material but varying diameter (the current remaining the same) will be inversely proportional to the fourth power of the diameters.*

(*a*.) Suppose a wire at any point to become reduced to *half* its diameter. The cross-section will have an area $\frac{1}{4}$ as great as in the thicker part. The resistance here will be 4 times as great, and the number of heat units developed will be 4 times as great as in an equal length of the thicker wire. But 4 times the amount of heat spent on $\frac{1}{4}$ the amount of metal will warm it to a degree 16 times as great ($16 = 2^4$).

(*b*.) A thin platinum wire, heated white-hot by a current, is sometimes used in surgery, instead of a knife, as it sears the ends of the severed blood vessels and thus prevents hemorrhage. Platinum is chosen on account of its infusibility, but even platinum wires are fused by too strong a current. Carbon is the only conductor that resists all attempts at fusion (§ 466).

(*c*.) Sometimes stout conducting wires are laid from a battery at a safe distance to a fuse connected with a blast of powder or other explosive. In the fuse, is a thin platinum wire, forming part of the electric circuit. The fuse is ignited by heating the platinum wire by sending the current through it. Such methods are frequently used in the operations of both peace and war.

473. Electric Motors.—*An electric motor is a device for converting the energy of an electric current into motive power by means of electro-magnets.* Illustrative apparatus of this kind may be found in many school laboratories or will be gladly supplied by dealers in philosophical apparatus. But the best electric motors are the now common dynamo electric machines or slight modifications thereof. Such "electro-magnetic engines" are rapidly coming into use for operating sewing machines and other light machinery, the current being supplied indirectly by a storage battery or directly by a voltaic battery or dynamo. Some "Electric Light and Power Companies" now run such motors on their arc light circuits, selling current to some for power and to others for light. In many cases where it is undesirable to use a steam engine, an electric motor may be made available. Such motors, up to the capacity of 40 H. P., are now in the market. Some of them have been successfully and economically used in propelling street railway cars.

474. Electric Transmission of Power.—A water fall, perhaps at a point not easily accessible, may be made to turn a turbine or other water wheel, which shall drive a dynamo, which shall generate a current, which shall be carried by wire to some available point and there converted into mechanical power again by means of an electric motor. Thus, an otherwise waste water-power may be made a source of profit. The scheme of thus distributing part of the power of Niagara over the State of New York has been seriously considered. It may be possible (as a profitable commercial undertaking) to burn cheap fuel *at the coal mine* for running large stationary

engines and thus deliver the power to consumers at great distances.

475. The Watt.—The electric unit of power (rate of doing work) is called a watt. *A watt is the amount of power conveyed by a current of one ampere through a difference of potential of one volt.* It equals $(10^{-1} \times 10^{8} =)\ 10^{7}$ ergs or $\frac{1}{746}$ horse-power,

$$W = C \times E = \frac{E^2}{R} = C^2 R,$$

in which W equals the number of watts; C, the number of amperes; E, the number of volts and R, the number of ohms.

For example, if the difference of potential (Appendix M, [4 *a*.]) between the terminals of an arc lamp that is supplied with a ten ampere current be 45.8 volts, how much of the power used in driving the dynamo is consumed in the lamp?

$W = C \times E = 10 \times 45.8 = 458$, the number of watts.
$458 \div 746 = 0.614$, the number of horse-powers.

(*a*.) The formula $W = C \times E$ is determined by the definition of the watt. From Ohm's law, we see that $C = \frac{E}{R}$. Substituting this value of C, the formula becomes $W = \frac{E}{R} \times E = \frac{E^2}{R}$, as above. This shows that *the power varies as the square of the E. M. F. when the resistance remains constant*, or that *the power varies inversely as the resistance when the E. M. F. remains constant.*

(*b*.) $W = C \times E$. But $E = C\,R$. Substituting this value of E, the formula becomes $W = C \times C\,R = C^2 R$, as above. This shows that *the power varies as the square of the current when the resistance remains constant* or that *the power varies as the resistance when the current remains constant.*

476. Relation of Conductors to E. M. F.— This subject may be well studied by means of an example. The energy of a ten ampere current with an E. M. F. of fifty volts is equal to that of a five ampere current with an E. M. F. of one hundred volts.

$$W = C \times E = 10 \times 50 = 100 \times 5 = 500.$$

These equivalent currents (500 watts each), flowing through similar wires, will develop widely different quantities of heat. If we take any convenient wire, say one of fifteen ohms, the heat developed in each case will be as follows:

$$H = C^2 \times Rt \times 0.24. \quad (\S\ 471.)$$

$10^2 \times 15 \times 0.24 = 360$, the number of heat units *per* second.
$5^2 \times 15 \times 0.24 = 90$, " " " "

In other words, the same electric energy develops only one-fourth as much heat with the current of high electromotive force as it does with the current of low E. M. F., the same wire being used. It is easily evident that a great saving in the cost of conductors may be made possible by the use of currents of high E. M. F. (See § 474.) But such currents are more dangerous to handle and require careful insulation and special precautions to lessen the risk of serious accident.

Exercises.

1. What shorter name may be given for a volt-ampere?

2. What electrical horse-power is required to send a current of 10 amperes through 10 arc lamps (in series) each having a resistance of 4.476 ohms? *Ans.* 6 H. P.

3. How many joules will be developed per minute by a 10 ampere current in a lamp of 4.42 ohms resistance? *Ans.* 26520 joules.

4. How many calories will be developed in a 40 ohm incandescence lamp by the passage of a current of 1.2 amperes through it for a minute? *Ans.* 82.944 calories.

5. Find the mechanical equivalent (in foot-pounds) of the work done by a 5 ampere current working for a minute against 100 ohms resistance? *Ans.* 110600¼ foot-pounds.

6. A 30,000 watt dynamo develops an E. M. F. of 3000 volts. What is the current strength? *Ans.* 10 amperes.

7. One coulomb of electricity, in passing from A to B, does one joule of work. What is the difference of potential between A and B?

8. The difference of potential between the two terminals of an arc lamp was found to be 37.7 volts. A 25 ampere current was passing through the lamp. What is the power consumed in the lamp? *Ans.* 942.5 watts, or 1¼ H. P.

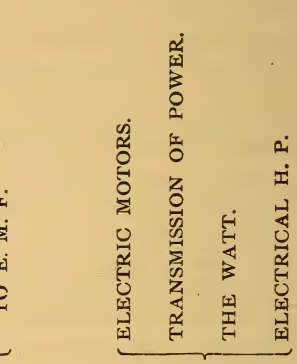
9. A certain Edison incandescence lamp has a resistance of 125 ohms. The difference of potential between the terminals of the carbon is 110 volts. (*a.*) What is the current strength? (*b.*) What amount of heat is developed in the lamp *per* second?

Ans. (*a.*) 0.88 ampere; (*b.*) 23.23 lesser calories.

10. A Grove cell has an E. M. F. of 1.9 volts and a resistance of 0.4 ohm. Its plates are joined, first, by a 3 ohms wire; second, by a 30 ohms wire. (*a.*) What is the current in each case? (*b.*) What amount of heat is developed in the cell in each case?

Ans.
- (*a.*) .559 amperes in first case.
- .0625 " " second case.
- (*b.*) .125 joules " first case.
- .00625 " " second case.
- About 80 times as much.

Recapitulation.—To be amplified by the pupil for review.



Review Questions and Exercises.

1. (*a.*) Give the laws for pressure of liquids and (*b.*) explain each by some fact or experiment.

2. (*a.*) What is a natural magnet? (*b.*) An artificial magnet? (*c.*) How does a magnet behave toward soft iron? (*d.*) How does one magnet behave toward another magnet?

3. Give the facts in regard to the variation of the magnetic needle.

4. (*a.*) What are conductors in electricity? (*b.*) In what ways may electrical separation be effected?

5. (*a.*) What conditions in the construction and erection of lightning-rods are necessary to insure safety from lightning? (*b.*) Give the elements of a simple voltaic cell and (*c.*) the electric condition of those elements within and without the liquid.

6. (*a.*) A body weighs at the surface of the earth 1014 lb.; what would it weigh 1200 miles above the surface? (*b.*) Give the velocity of water issuing from an orifice, under a head of 81 feet. (*c.*) If 5 quarts of water weigh as much as 7 of alcohol, what is the specific gravity of the alcohol?

7. Find the kinetic energy of a 25 lb. ball that has fallen 3600 feet in vacuo. *Ans.* 90,000 foot-pounds.

8. Give the fundamental principle of Mechanics and illustrate its application by one of the mechanical powers.

9. (*a.*) Over how high a ridge can you continuously carry water in a siphon, where the minimum range of the barometer is 27 inches? (*b.*) Explain.

10. (*a.*) What is specific gravity? (*b.*) How do you find that of solids? (*c.*) What principle is involved in your method?

11. (*a.*) How much water per hour will be delivered from an orifice of 2 inches area, 25 feet below the surface of a tank kept full of water, not allowing for resistance? (*b.*) Give the law of magnetic attraction and repulsion. *Ans.* 14,998.44 gal.

12. (*a.*) State what you have been taught concerning the dipping needle. (*b.*) Define and illustrate magnetic induction.

13. (*a.*) Give the law of electric attraction and repulsion and illustrate by the pith-ball electroscope. (*b.*) Define conductors and non-conductors, electrics and non-electrics. (*c.*) Illustrate by an example of each.

14. (*a.*) Explain (by figures) electric induction. (*b.*) Explain the charging of a Leyden jar. (*c.*) When charged, what is the electric condition of the outside and inside of the jar?

15. (*a.*) Give the sources of atmospheric electricity and (*b.*) the effects of lightning.

16. (*a.*) What is the effect of breaking a magnet? (*b.*) Give a theory of magnetism that is competent to account for the properties of magnets, broken or unbroken.

17. (*a.*) How do soft iron and tempered steel differ as to susceptibility to magnetism? (*b.*) Describe one method of magnetizing a steel bar.

18. The influence of the earth's magnetism upon a magnetic needle is merely directive. (*a.*) Explain what this means. (*b.*) Show why it is so.

19. (*a.*) What is meant by electromotive force? (*b.*) Describe Grove's battery and its mode of action. (*c.*) Why are battery zincs generally amalgamated?

20. (*a.*) Describe Oersted's apparatus and (*b.*) tell what its use teaches. (*c.*) Describe the construction of the astatic galvanometer.

21. (*a.*) Describe an electro-magnet and (*b.*) tell what its advantages are. (*c.*) State the principle of the electric telegraph.

22. (*a.*) Describe a Ruhmkorff's coil and (*b.*) explain its action.

23. (*a.*) Define electrolysis and electrolyte. (*b.*) Describe the electrolysis of water. (*c.*) Give a clear account of some branch of electro-metallurgy. (*d.*) What is meant by the terms *electro-positive* and *electro-negative?*

24. (*a.*) Define physics. (*b.*) Name and define the three conditions of matter. (*c.*) What do you understand by energy? (*d.*) Explain what is meant by foot-pound.

25. (*a.*) What condition of the atmosphere is desirable for experiments in frictional electricity? (*b.*) Why? (*c.*) How could you show, experimentally, that there are two opposite kinds of electricity?

26. (*a.*) Describe the experiment with Faraday's bag and (*b.*) state what it teaches. (*c.*) Describe the dielectric machine and (*d.*) explain its action.

27. In an air-pump, the capacity of the cylinder is one-fourth that of the receiver. Under ordinary atmospheric conditions, they together contain 62 grains of air. Find the capacity (*a.*) of the receiver, (*b.*) of the cylinder. After 5 strokes of the piston, (*c.*) how many grains of air would be left in the receiver? What would be its tension (*d.*) in pounds per square inch? (*e.*) In *Kg.* per *sq. cm.?* (*f.*) In inches of mercury? *Ans.* (*e.*) 327.68 *g.*

28. (*a.*) Supposing we had two Leyden jars, one charged on the inside with positive electricity and the other with negative on the

inside; the two jars being insulated, can the jars be fully discharged by connecting the inner coats? (*b.*) Give reasons for your answer.

29. In a vessel having the dimensions of a cubic foot, sulphuric acid (sp. gr. = 1.83) stands eight inches high; give the pressure on the bottom and each side.

30. The lever of a hydrostatic press is six feet long, the fulcrum being at the end and one foot from the piston rod. The diameter of the tube is one inch; that of the cylinder, ten inches. The power is 25 lb.; give the effect. (See Appendix A.)

31. Find the joint resistance of three conductors of 10, 12 and 18 ohms arranged in multiple arc. *Ans.* 4.18 ohms.

32. (*a.*) Define equilibrium and its kinds. (*b.*) Give examples. (*c.*) How does the centre of gravity of any system, acted upon by an exterior force, move? (*d.*) Give an example.

33. (*a.*) Figure a simple barometer. (*b.*) Explain why the mercury stands above its level. (*c.*) What atmospheric pressure will sustain a column of mercury 24 inches high?

34. (*a.*) How is it proved that air has weight? (*b.*) What is the weight of air in a room 30 feet long, 20 feet wide and 10 feet high.

35. When a 1000 gram flask, containing 700 *g.* of water, was filled with the fragments of a mineral, it weighed 1450 *g.* Give the specific gravity of the mineral. *Ans.* 2.5.

36. A tank measuring 1 meter each way is filled with water: what will be the pressure on the bottom and sides?

37. (*a.*) What is meant by kinetic energy? (*b.*) By potential energy?

38. Two inelastic bodies are moving in opposite directions, one weighing 31 grams and having a velocity of 24 meters per second, the other weighing 22 grams and having a velocity of 18 meters per second: what is the united energy (*a.*) before and (*b.*) after impact? *Ans.* (*a.*) 1.27; (*b.*) 0.137 kilogrammeters.

39. Regarding the same bodies as moving in the same direction, what would be the energy (*a.*) before and (*b.*) after impact?

40. (*a.*) Draw a simple figure showing the essential parts of an air-pump and (*b.*) explain the process of forming a vacuum. (*c.*) If the capacity of the barrel be $\frac{1}{4}$ that of the receiver, how much air will remain in the receiver at the end of the fourth stroke of the piston? and (*d.*) what would be its elastic force compared with that of the external air? *Ans.* (*d.*) $\frac{256}{625}$.

41. The current of a Grove's battery with a certain resistance in the circuit is known to be $\frac{1}{6}$ ampere. Passing this current through a sine galvanometer, the coils had to be turned 9° to bring them parallel with the needle. (See Appendix L [2]). Some of the resistance

being removed, it is found that the coils have to be turned 70° to bring them parallel. What is the current in the latter case?

Ans. 1 ampere.

42. If a positively electrified ball be hung at the centre of a room, its charge will attract an equal amount of — electricity to the walls of the room. To what common piece of physical apparatus is this arrangement analogous?

43. What length of No. 6 pure copper wire (B. & S.) will have a resistance of 1 ohm? (See Appendix I.) *Ans.* 2433.09 ft.

44. If a foot of pure copper wire weighing 1 grain has a resistance of 0.2106 ohm and 20 feet of commercial copper wire weighing 150 grains has a resistance of 0.613 ohms, what is the percentage conductivity of the latter as compared with pure copper?

Ans. 91.6 per cent.

45. Sketch an arrangement by which a single line of wire can be used by an operator at either end to signal to the other; the condition of working being that whenever either operator is not sending a message, his instrument shall be *in circuit* with the line wire and *out of* circuit with the battery at his end.

46. Calculate, by Joule's law, the number of heat units developed in a wire whose resistance is 4 ohms when a steady current of 0.14 ampere is passed through it for ten minutes. *Ans.* 11.2 units of heat.

47. A dynamo has an E. M. F. of 839 volts and an internal (or interpolar) resistance of 10.9 ohms. Find the current strength when the external resistance is 73 ohms. *Ans.* 10 amperes.

48. I have 48 cells, each of 1.2 volts E. M. F. and each of 2 ohms internal resistance. What is the best way of grouping them together when it is desired to send the strongest possible current through a circuit whose resistance is 12 ohms? *Ans.* Group them three abreast.

49. The current from a certain dynamo (E. M. F. = 839.02 volts) was sent through a series of 16 arc lamps each having a resistance of 4.51 ohms. The line wire had a resistance of 0.8 ohm. The current measured 10.04 amperes. What was the resistance of the dynamo? *Ans.* 11.32 ohms.

50. Immediately after the discharge of a Leyden jar, the potential of its knob is zero. It, however, begins to rise and soon has a value that is a considerable part of the potential before discharge and with the same sign. Explain this.

51. What three varieties of energy appear when a Leyden jar is discharged?

52. How many heat units (calories) will be developed by a 10 ampere current flowing through a coil of 50 ohms resistance in a quarter of an hour? *Ans.* 1,080 calories.

53. A current of 9 amperes worked an electric arc light and on measuring the difference of potential between the two carbons by an electrometer it was found to be 140 volts. What was the amount of power absorbed in the arc? *Ans.* 1.69 H. P.

54. If the cells represented in Fig. 252 have each an internal resistance of 4 ohms, what is the resistance of the external circuit, G, if the battery is working at its greatest possible efficiency? *Ans.* 6 ohms.

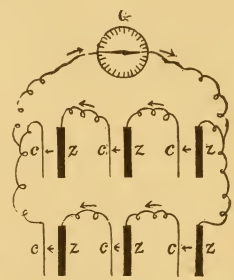


FIG. 252.

55. The same strength of current that will heat an inch of platinum wire to whiteness will similarly heat a yard of the same wire. Explain why it is necessary to use more cells thus to heat a yard than it does to heat an inch of the wire.

56. Five Daniel cells, each with an E. M. F. of 1.1 volts and an internal resistance of 2.2 ohms are joined in series. The external circuit consists of 16743 feet of No. 14 copper wire (B. & S.) (See Appendix I.) (*a.*) What is the resistance of the external circuit? (*b.*) What is the current strength? *Ans.* (*b.*) 0.1 ampere.

57. Show that with an unlimited number of cells like that just described, joined in series, the current cannot exceed 0.5 amperes.

58. What is the total energy of the current of the dynamo, operated as described in Exercise 1, page 349? *Ans.* { 8417.94 watts. 11.28 horse-power.

59. Explain the use and construction of a relay.

60. Suppose 1000 incandescence lamps to be placed parallel in the circuit of a dynamo. Each lamp has a hot resistance of 50 ohms and requires a current of 1 ampere. (*a.*) What will be the current strength developed by the dynamo? (*b.*) What is the resistance of the lamp circuit, ignoring the resistance of the leading wires? (*c.*) What is the necessary difference of potential between the binding posts of the dynamo? (*d.*) If the resistance of the dynamo itself is 0.005 ohm, what is the total E. M. F.? (*e.*) How many watts will be expended in each lamp? (*f.*) If 500 of the lamps be turned off (open circuited), what will the resistance of the lamp circuit become? (*g.*) If the E. M. F. of the dynamo be kept constant by change of speed or otherwise, what will be the current developed by the dynamo with the 500 lamps? (*h.*) What will be the current then supplied to each lamp?

Ans. (*a.*) 1000 amperes; (*b.*) 0.05 ohm; (*c.*) 50 volts; (*d.*) 55 volts; (*e.*) 50; (*f.*) 0.1 ohm; (*g.*) 523.81 amperes; (*h.*) 1.047 amperes.

HONORARY PROBLEMS.

1. Two incandescence lamps with resistances of 16.9 and 32 ohms respectively were joined in series with a series of 40 similar voltaic cells having a total resistance of 20 ohms. The current measured 1.16 amperes. What will be the strength of current that a series of 60 such cells will send through a series of four lamps having resistances of 16.9, 32, 20 and 16 ohms respectively?

Ans. 1.043 amperes.

2. What would have been the strength of current in this case if the area of the battery plates had been doubled, all things else remaining the same? *Ans.* 1.2 amperes.

3. It required 15.3 H. P. to drive a certain dynamo that had a resistance of 10.5 ohms and developed a current of 10 amperes through an external resistance of 73 ohms. (The "duty" of a dynamo is the ratio of the total electrical energy developed to the work performed in turning the armature in the magnetic field). What is the *duty* of the dynamo in question? *Ans.* 73 per cent.

4. The "commercial efficiency" of a dynamo is the ratio of the electrical energy appearing in the external circuit to the work performed in turning the armature in the magnetic field. What is the *commercial efficiency* of the dynamo above mentioned?

Ans. 64 per cent.

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